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Education and Digital Societies for a Sustainable World

Edited by
Sandro Serpa and Maria José Sá

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Editorial

Education and Digital Societies for a Sustainable World

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1. Introduction

The Topic "Education and Digital Societies for a Sustainable World" falls within the Digital Society Topic, which materializes in various dimensions, considering distinct social contexts. If, on the one hand, these processes, already being implemented, raise profound challenges for social inclusion, they are, on the other hand, opportunities to transform educational processes for the global development of individuals (both in informal and formal educational contexts), enabling better preparation for digital societies that are truly based on a sustainable world, in accordance with the fulfilment of the global Sustainable Development Goals [1]. To achieve this, effective efforts must be made towards reducing old inequalities and not encouraging new ones in an all-inclusive society. This article collection emerges in this context and seeks—in a disciplinary, multidisciplinary, and transdisciplinary way, through different types of manuscripts, research articles, meta-analyses, or reasoned reflections—to add in a reasoned way to the promotion of scientific dialogue in order to contribute to paving the way towards education and digital societies for a sustainable world.

2. Presentation of the Publications

This Topic involves five MDPI participating journals (*Digital*, *Education Sciences*, *Societies*, *Social Sciences*, and *Sustainability*). The 28 papers published on this Topic (22 articles, 1 project report, 4 reviews, and 1 systematic review) in these journals (*Digital* (1), *Education Sciences* (6), *Social Sciences* (1), *Societies* (3), and *Sustainability* (17)), amounting to a total of 138 submissions, demonstrate aspects such as the demand for quality, internationalization, and cross disciplinarity, in line with Lyon [2] (p. 1), who advocates that "[. . .] sustainability as a science can be distilled into cross-disciplinary approaches that highlight the connections across natural sciences and human sciences". This establishes the current relevance of this Special Issue for the global scientific community. We have a total of eighty-six authors, with a minimum of one author, a maximum of six authors, and an average of three authors per paper. The authors of the manuscripts are affiliated with various institutions in the following 22 countries: Australia, Canada, Chile, China, Estonia, France, Germany, Greece, Indonesia, Italy, Japan, Korea, Lithuania, Malaysia, Pakistan, Philippines, Portugal, Russia, Saudi Arabia, South Africa, Spain, and Turkey [1].

Albeit not exhaustive, as the reader will have the opportunity to deepen this knowledge by reading these publications in full, a brief presentation follows of the objectives of each of the publications that make up this Topic, by type of publication, making it possible to realize the great variety and richness of the areas studied.

2.1. Section I—Articles

Yandug et al.'s [3] article "A Conjoint Analysis Approach, Implications, and Mitigation Plans in Analyzing Students' Preferences for Online Learning Delivery Types during the

COVID-19 Pandemic for Engineering Students: A Case Study in the Philippines" examines the challenges faced by engineering students in the Philippines when the pandemic forced them to switch from face-to-face classes to online learning. The authors found that students struggled with the unfamiliar online environment and technical difficulties. This led to dissatisfaction and a negative impact on their academic performance.

The study "A Multidimensional Evaluation of Technology-Enabled Assessment Methods during Online Education in Developing Countries", by Khattak et al. [4], delves into the challenges of using technology for assessments in online education in developing countries. Focusing on Pakistan, the authors analyze how well technology works to assess student learning. The researchers surveyed nearly 1000 students from over 100 public and private engineering universities. Subsequently, they narrowed down a list of possible assessment methods and the factors that influence those methods. To do this, they considered the perspectives of various stakeholders, including policymakers, faculty members, and students, using a method called multi-actor multi-criteria analysis (MAMCA).

According to Miranda et al. [5], in their study "An Investigation of Learning Needs in the Mining Industry" on training needs within the mining industry, mining is an inherently hazardous field with a significant risk of accidents. The authors emphasize that these accidents can be prevented through the implementation of proper safety measures. They argue that mining companies have a critical responsibility to prioritize these measures to safeguard the wellbeing of their workers and guarantee the long-term viability of the industry. Their research specifically focuses on training-related safety measures within the context of the ERASMUS+ project DigiRescueMe.

Tintori et al. [6] examine the increased risk of online dangers for children due to the surge in Internet usage during the COVID-19 pandemic. In their study "Children's Online Safety: Predictive Factors of Cyberbullying and Online Grooming Involvement", the authors analyze cyberbullying and online grooming among primary school students in Rome. Their research identifies factors that make children more vulnerable to these problems.

In the article "Chronological Progress of Blockchain in Science, Technology, Engineering and Math (STEM): A Systematic Analysis for Emerging Future Directions", Dziatkovskii et al. [7] explore the transformative potential of blockchain technology in the context of Industry 4.0. The authors argue that this new digital landscape is shaping the future of humanity, which aligns perfectly with the United Nations Sustainable Development Goals (SDGs) on health and wellbeing (SDG3) and sustainable cities and communities (SDG11). Their primary goal is to shed light on how STEM fields are embracing blockchain technology.

The study by Sá et al. [8], entitled "Citizen Science in the Promotion of Sustainability: The Importance of Smart Education for Smart Societies", explores the concept of Society 5.0, particularly in relation to digitization and sustainability. These authors argue that the achievement of Society 5.0 is not guaranteed. They point out that the changes it brings, along with its benefits, also carry risks. These include the widening of existing social inequalities within and between countries, as well as new inequalities in social, cultural, economic, and political spheres.

In the article "Connecting Classrooms with Online Interclass Tournaments: A Strategy to Imitate, Recombine and Innovate Teaching Practices", Araya et al. [9] argue that online interclass tournaments can be a powerful tool for achieving the educational goals set by the United Nations Educational, Scientific and Cultural Organization (UNESCO) and modern curricula. The authors analyze four online interclass tournaments they have implemented over the past decade. This long-term perspective is essential to assess the long-term viability of new teaching methods. Their study found that interclass tournaments are practical for implementation in schools, promote a promising approach to teaching with a greater integration of subjects, and encourage the imitation, recombination, and innovation of teaching practices, and thus could present a viable strategy to promote educational innovation and improve the overall quality of education.

In the article "Game On, Reflection On: Reflection Diaries as a Tool for Promoting Reflection Skills in Geography Lessons", by Baßeng and Budke [10], the researchers explore how reflection diaries could help students develop critical thinking skills in geography lessons that used digital games. The researchers found that the diary itself played a key role: by prompting reflection, it helped students step outside of the mindset of being a player and analyze the game more critically. The diary, integrated into the lessons, offered specific prompts to guide students' reflections on the game's content and challenge any geographical misconceptions they might have formed while playing.

Zhu et al. [11] introduce a new approach to finding relevant courses and jobs for students and employees, named the Graph-Community-Enabled (GCE) model, to address the challenge of matching the skills required for jobs with individuals educated in the relevant courses. In their article titled "Graph-Community-Enabled Personalized Course-Job Recommendations with Cross-Domain Data Integration", the researchers use a technique called community detection to identify groups of related skills. This allows the model to link courses to relevant jobs based on the skills they target.

In the article "Making Urban Water Management Tangible for the Public by Means of Digital Solutions", Stein et al. [12] explore the growing use of digital tools in water management, focusing on two case studies in Paris and Berlin. These solutions are seen as a promising way to improve decision making, automate processes, and ultimately achieve the United Nations SDGs related to water resources.

Davidavičius and Limba [13], in "Recognition of Digital Content Needs for Inbound Marketing Solutions", set out to explore how people behave when consuming content in the context of inbound marketing. In this study, the authors are particularly interested in understanding why people need content and what motivates them to seek it out, especially for products that take a long time to use or consume.

In their study entitled "Relationship Recognition between Knowledge and Ability Based on the Modularity of Complex Networks", Zou, Sun, and Zhou [14] introduce a new system for understanding how knowledge relates to an individual's abilities. This system is based on the specific structure of modules within complex networks. The authors designed a model called the Knowledge Cognitive Interdependent Network (KCIN) to analyze these relationships.

In the article "Requirements of Modern Russian Agricultural Production for Digital Competencies of an Agricultural Specialist", Khudyakova et al. [15] aim to identify the digital skills most in-demand in today's Russian agricultural industry. The results stemming from their analysis of the existing curricula in Russian agricultural universities revealed the universities' inadequacy in meeting the contemporary demands of agricultural production. This underscores the necessity for a thorough review of the curricula.

Li and Jiang, in their article "Research on the Teaching Reform of Inorganic Chemistry Based on SPOC and FCM during COVID-19", ascertain that the pandemic has brought about a fundamental change in the Chinese education system, requiring teachers and students to adapt to online learning in a short period of time. The flipped classroom model can compensate for this deficiency. This study aimed to investigate the effectiveness of flipped learning based on small private online courses (SPOCs) and put forth explicit criteria for its reuse in higher education [16].

Based on data from the 2018 Teaching and Learning International Survey (TALIS), Jung and Woo [17] examine, in their article titled "Structural Model Analysis of Factors Affecting Sustainable Teacher Job Satisfaction in Korea: Evidence from TALIS 2018", how factors such as preparedness, confidence in one's abilities (self-efficacy), and career motivation influence teachers' job satisfaction in Korea. Following the findings of their study, the authors put forth recommendations for enhancing sustainable job satisfaction, self-efficacy, and career motivation for teachers within teacher education programs.

The article "Students' Environmental Care Attitude: A Study at Adiwiyata Public High School Based on the New Ecological Paradigm (NEP)" by Wibowo et al. [18] examines the environmental attitudes of students in Adiwiyata, Indonesia, in schools utilizing a program known for promoting environmental responsibility. Their study emphasizes the importance of fostering positive environmental attitudes, examines how effectively these schools integrate environmental education into their curricula, and explores potential differences in environmental concerns between male and female students.

In their study titled "Students' Perceptions towards the Role of Online Teaching Platforms in Enhancing Online Engagement and Academic Performance Levels in Palestinian Higher Education Institutions", Tarazi and Ruiz-Cecilia [19] investigate how online teaching platforms affect learning and teaching from the perspective of undergraduate English students and explored the relationship between students' engagement in online learning and their academic performance.

The article "Teachers' Frequency of ICT Use in Providing Sustainable Opportunity to Learn: Mediation Analysis Using a Reading Database" by Hu and Hu [20] examines the relationship between how often teachers use information and communication technology (ICT) in their classrooms and how they provide learning opportunities that benefit students in the long term (sustainable learning opportunities). This article focuses on whether teachers' confidence in their abilities (self-efficacy) and their ability to use different teaching methods to meet individual student needs (flexible strategy use/adaptive instruction) play a significant role in this relationship.

The article by Yu et al. [21], titled "The Cost of Caring: Compassion Fatigue Is a Special Form of Teacher Burnout", explores the emotional toll that teaching can take. The authors surveyed over 1500 teachers in China, concluding that many experience compassion fatigue, a condition in which caring for students leads to emotional and professional burnout, as well as analyzing the differences in compassion fatigue between teachers from primary and secondary schools and its repercussions on students.

In their study "The Development and Evolution of Digital Leadership: A Bibliometric Mapping Approach-Based Study", Karakose et al. [22] set out to explore the intellectual landscape and historical development of the field of digital leadership, with digital leadership acting as a broad term encompassing various leadership styles, and considered them as interchangeable concepts. The findings of their study unveil a gradual expansion and diversification in digital leadership research. This evolution enhances comprehension of the digital leadership research domain, offering insights into its conceptual framework and thematic progression.

Wang and Si [23], in their article "The Intersection of Public Policy and Public Access: Digital Inclusion, Digital Literacy Education, and Libraries", explore how Chinese libraries can better serve the public in the digital age, focusing on the critical role that libraries play in bridging the digital divide by equipping people with the skills they need to participate fully in the digital world to build a more inclusive and equitable digital society. The findings highlight the policy framework, programs, and tactics aimed at advancing digital literacy and inclusion, stressing the pivotal role of libraries in spearheading efforts to promote digital inclusion and encourage active user participation.

In the study by Sofwan, Habibi, and Yaakob [24], titled "TPACK's Roles in Predicting Technology Integration during Teaching Practicum: Structural Equation Modeling", the researchers showcase the results of their research on the influence of a specific type of knowledge, namely technological pedagogical and content knowledge (TPACK), on how teacher candidates integrate technology into their students' learning experiences.

2.2. Section II—Project Report

In their study "Okanagan Waterways Past, Present and Future: Approaching Sustainability through Immersive Museum Exhibition", Dulic et al. [25] describe a research project and exhibition designed to raise awareness of the connection between people and water. This project, located in the Okanagan Syilx area, aims to inspire sustainable water use. It demonstrates how combining scientific research, academic knowledge, and practical applications can provide a deeper understanding of water sustainability specific to a particular place.

2.3. Section III—Reviews

Sá and Serpa [26], in their review "Metaverse as a Learning Environment: Some Considerations", explore the potential of the metaverse to revolutionize education. The authors examine the challenges and opportunities of this virtual world, focusing on how it can create a more relevant and effective learning experience. Their discussion emphasizes the importance of conducting and monitoring research studies to track the impact of the metaverse on education.

In the review titled "Reconceptualizing Disabilities and Inclusivity for the Postdigital Era: Recommendations to Educational Leaders", Uleanya [27] emphasizes the critical role of inclusive education in achieving global sustainable development. Uleanya's research examines how scientific publications in South Africa represent the concept of inclusive education. The paper suggests that, in distance education, a shortage of technological resources can be seen as a form of technological disadvantage. Therefore, there is a need to consider inclusive education in relation to technological disadvantages.

Siddiqui and Schultze-Krumbholz [28] conducted a review titled "Successful and Emerging Cyberbullying Prevention Programs: A Narrative Review of Seventeen Interventions Applied Worldwide". Their research focuses on evaluating existing cyberbullying prevention programs. These programs achieved success by engaging teachers through professional development and implementing a comprehensive, school-wide approach.

Dron's [29] review, "The Human Nature of Generative AIs and the Technological Nature of Humanity: Implications for Education", explores the implications of widely deployed generative AIs (GAIs) for education and society as a whole. It examines how GAIs might influence and even reshape our collective intelligence and analyzes various approaches to mitigating the potential drawbacks of GAIs while maximizing their potential benefits in education.

2.4. Section IV—Systematic Review

Finally, Falcón-Linares et al. [30], in their review "Impact of Social Media on Adolescence: Mapping Emerging Needs to Build Resilient Skills", point to a growing body of research demonstrating the link between social media use and adolescent mental health, examining the factors that make adolescents more vulnerable, potential risks, comorbidity, and elements that can predict either a decline or an improvement in their mental wellbeing.

3. Conclusions

We would like to reiterate our deepest thanks to everyone who, in various ways, contributed to the success of this Special Issue. First of all, we would like to thank all of the authors who submitted their manuscripts, showing their confidence in our editorial work as Guest Editors. We would also like to thank the Editors-in-Chief and Editors of the journals involved, as well as the reviewers, who devoted their time and expertise to providing rigorous, constructive, and highly pertinent assessments, contributing significantly to improving the scientific quality of the manuscripts submitted. Last but not least, we would like to thank the Editorial Office for its invaluable support throughout the development of this Special Issue.

In summary, this set of high-quality publications made available to the reader has the potential to contribute to a rigorous and well-founded discussion on the Topic "Education and Digital Societies for a Sustainable World". As Lyon [2] rightly points out, cross-disciplinary work is essential if sustainability is to be approached in a fruitful way, and we agree with his position as someone who emphasizes that, in addition to the three traditional pillars of sustainability—environmental, social, and economic—there may be a need to add other pillars, such as those relating to human, culture, or security aspects, considering that "The presence of more pillars aids in the shift from science to application to strategy for management" [2] (p. 1). Ultimately, by integrating this complementarity between these dimensions, heuristic capacities for the scientific apprehension of reality can be expanded.

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Article

A Conjoint Analysis Approach, Implications, and Mitigation Plans in Analyzing Students' Preferences for Online Learning Delivery Types during the COVID-19 Pandemic for Engineering Students: A Case Study in the Philippines

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Abstract: Traditional face-to-face classes were replaced with online learning when the COVID-19 pandemic happened. Students were unfamiliar with the virtual setup, as well as the technological challenges, which led to dissatisfaction and affected their academic performance. This research study surveyed 230 engineering students and applied conjoint analysis to analyze their preferences in online learning delivery. Using SPSS Statistics software, we revealed the top three attributes for delivery type: interaction, flexibility, and proctored exam. In addition, the most favored combination from the generated stimuli was a form of blended mode delivery. The synchronous meetings and asynchronous activities allowed students to manage their time efficiently. It could be deduced from the findings that students highly preferred the combination considering learner–instructor, live chats, real-time lecture meetings, and automatic availability, with a focus on synchronous online learning modes. Higher education institutions may reflect on the results of this study to reassess the online learning environment they implement among students. Incorporating a student's learning style to determine the relationship between their preference for online learning delivery type will be helpful for further research through application and study extension. It is suggested that the perceptions of instructors and students enrolled under different learning modalities and their effectiveness should also be addressed. This is a recommendation for future research to consider. Especially near the end of the COVID-19 pandemic, traditional face-to-face learning was being implemented. Thus, future studies may want to consider an analysis of the behavioral intentions of students. On the other hand, analyses such as student behavioral intentions for the future applications of the different modalities and comparisons thereof may be conducted to enhance the implications for, policies of, and strategies of universities.

Keywords: online learning; conjoint analysis; delivery type; blended learning; learning type

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1. Introduction

Engineering is an occupation that covers different disciplines, such as mechanics, production, business operations, and more. Engineers use their science, mathematics, and logic knowledge to find a suitable solution to a problem. They weigh the pros and cons of various design options before selecting the one that best meets their needs [1]. According to Engineers Australia [2], "They improve the state of the world, amplify human capability and make people's lives safer and easier". From the U.S. Bureau of Labor and Statistics [3], the number of new jobs for engineers in the next ten years will be approximately 135,000, as projected since 2016. Having a bachelor's degree is considered enough to provide one with the needed background to enter the field of engineering [4]. In the Philippines, 17 universities have engineering programs accredited by the Accreditation Board for Engineering and Technology (ABET) [5], and this has proven essential for institutions as it shows that graduates of accredited programs will be equipped with the best practices to be globally competitive [6]. To become a professional, one must take licensure exams for specific engineering courses such as civil engineering and chemical engineering.

When the COVID-19 pandemic began in 2020, people had to adjust to working or studying in a virtual setup. Even though online learning was not new in the education sector, it was still a big challenge for students—especially those in developing countries. The transition from face-to-face to fully online was abrupt as students were more accustomed to having lectures, exams, classwork, and other outputs performed in a classroom setup. For example, higher education students at the Polytechnic University of the Philippines (PUP) Camarines Sur were concerned about student and faculty training to use digital platforms for online classes [7]. Different delivery methods are now being held virtually for courses, contrary to what teachers previously practiced. According to Martin and Oyarzun [8], some classifications that fit in the Philippine online education setting were synchronous, asynchronous, and blended online learning. As defined, synchronous online learning is a delivery method where content is delivered online and is accessible at any time, with real-time meetings for students to participate at the same time. Asynchronous online learning provides course content online where students are not required to join in real-time sessions. Blended online learning combines both modalities such that students and instructors can schedule convenient times to attend online meetings. According to the University of Waterloo in Canada, when deciding the online delivery method(s) to consider, it is vital to consider that some students may have other responsibilities at home that can prevent them from engaging in class at a particular time [9]. In the Philippines, only top and private universities have offered online classes as part of the curriculum for practice. However, challenges, setup, and implementation were not completely established before the COVID-19 pandemic.

Despite this advancement in technology and education, the Philippines still has not completely adopted the technological implementation of online learning. This is similar to other developing countries, especially with the abrupt changes during the COVID-19 pandemic. A study in Indonesia claimed that students' perceptions of online learning during the COVID-19 pandemic were that it was ineffective and unpleasant because not all students had the resources to access online materials smoothly [10]. Similar to the Philippines' situation, a survey by the Safe, Equitable, Quality, and Relevant (SEQuRe) Education Movement revealed that 71 to 72% of students and parents encountered problems attending classes online due to internet connection, gadgets, and distance learning expenses [11]. According to Baturay and Yukselturk [12], students' successes in online learning were subject to their satisfaction when their preferences were met. Balta-Salvador et al. [13] stated that engineering students were not satisfied with the quality of online learning education, which was correlated with their workspace conditions, and this had negatively affected their academic performance. Thus, a conjoint analysis approach was applied to determine engineering students' preferences for online delivery types. Little to no literature were available for preference analyses of online delivery types in the Philippines. Most of the existing literature has focused on the generalization of the population, rather than the specifics which could provide in-depth analyses and findings that could be extended to more aspects of management, strategies, and implementation-building.

A conjoint analysis approach is used as a research method to measure preferences beyond sales and marketing. It is a statistical technique based on surveys to determine the importance of given factors [14]. Several studies conducted pre-COVID-19 used a conjoint analysis approach to determine students' preferences concerning online learning. The results from Malarkodi et al. [15] showed that the top two reasons students in India preferred online learning were the flexibility of study location and study time. Similarly, the results obtained by Daghan and Akkonyulu [16] showed that a student's learning style was correlated with their preference for online learning environment. Another study from Turkey showed that students greatly valued the following employed technology characteristics: the learning materials provided by teachers, the interaction types between the instructor and students, and flexibility. In Serbia, students expressed that their preferred method of knowledge assessment was 100% online, as most students showed that they were more results-oriented [17]. In the Philippines, nursing students were surveyed about their preferences for clinical instructors and conveyed that the attributes of high value to them were the instructor's teaching capabilities [18].

A recent study by Agyeiwaah et al. [19] showed the attributes influencing student satisfaction regarding online education during the COVID-19 pandemic. Applying a quantitative method using principal component analysis, the attributes identified resulted in three factors:

"Factor 1: "Perspicuity and dependability", comprises items that explain the clarity, understandability, and safety of online learning. Factor 2, named "Stimulation and attractiveness", comprises items that explain how the online learning classroom is motivating, exciting, and attractive to students. And lastly, Factor 3, named "Usability and innovation", denotes how students find their new online learning classroom user-friendly and innovative".

The correlation matrix and regression analysis showed a significant association between these factors and student satisfaction. The hospitality and tourism students in Macau expressed that it was challenging to learn from home because of overwhelming interruptions. Accordingly, the degree to which the online learning environment is stimulating and attractive is the most crucial factor motivating one to engage.

Another qualitative study by Muthuprasad et al. [20] about students' perceptions of online learning during the COVID-19 pandemic showed that a significant percentage of the respondents stressed that online learning was not as effective as face-to-face learning classes. Most students preferred recorded classes, meetings with the instructor twice per week, a 1-week deadline for assignments, and other preferences. It also showed that students' most significant challenges were the technical aspects of online learning and their learning environments.

Moreover, in the study by Ong et al. [21], a conjoint analysis approach was used to determine students' preferred online learning attributes. They obtained results showing that industrial engineering undergraduate students placed the highest importance on the final requirement of the multiple-choice exam as it held one of the highest percentages for their final grade. The choice to delivering mixed synchronous and asynchronous online learning ranked fourth in their preferred attributes. Thus, it showed that students also prioritized guidance and learning at their own pace. To further decipher which delivery type fit a specific course subject depending on the preferences of students, this study proved its relevance.

Limited studies have expressed students' preferences for the general concept of online learning without further exploring their preferences for delivery type. Therefore, this paper aimed to determine the preferred delivery type for online learning engineering students and its attributes during the COVID-19 pandemic. Hence, conjoint analysis with an orthogonal design was utilized in this context. The following research questions were created alongside the research objectives:

1. What are the preferred attributes and specifications of engineering students among interactions, flexibility, communication, materials, assessments, and proctored exams?

2. What are the least preferred attribute combinations among students?

3. Based on the outcome and findings, what mitigation plans would be created for students for student experiences, technological issues, and course concerns?

Moreover, this study will help higher education institutions deliberate the delivery types instructors should consider executing to move toward better quality education from an educational point of view.

2. Methodology

2.1. Research Design

The overall conceptual framework of this study is shown in the below figure. In the first stage of the study, attributes and their levels were determined (Table 1), formulating the conjoint design and creating the survey questionnaire based on the generated stimuli. From this, students rated the generated combinations of stimuli through a seven-point Likert scale. The preliminary distribution of the survey determined the acceptability of the orthogonal design of the study based on the initial Pearson's R-value. A total of 18 questions were created, as seen in Table 2. These attributes were presented using Google Forms in the data gathering process (sample in Figure 1). The second stage followed the entire survey distribution through social media platforms and obtained the data. The last stage was the application of the conjoint analysis and interpretation of the results to determine the preferred attributes for the delivery type of online classes for engineering students at private universities.

Table 1. Attributes and levels for online learning delivery type.

Attributes	Levels	Citation
Interaction	Learner–instructor Learner–content Learner–learner	Moallem [22]
Flexibility	Immediate Self-paced Scheduled	Soffer, Kahan, and Nachmias [23]
Communication	Discussion board Live chat Consultation meeting	Xie, H.; Liu, W.; Bhairma, J.; and Shim, E. [24]
Material	Pre-recorded lecture Real-time lecture meeting Reading materials and supplementary videos	Muthuprasad, T.; Aiswarya, S.; Aditya, K.S.; and Jha, G.K. [20]
Assessment	Automatically available Adaptive release	Martin, F. and Whitmer, J.C. [25] University of Waterloo [9]
Proctored exam	Yes No	Ong et al. [21]

Table 2. Student profiles.

Characteristics	Category	N
Year Level	First year	51
	Second year	56
	Third year	100
	Fourth Year	19
	Fifth year	4
School	School of Chemical, Biological, and Materials Engineering and Sciences (http://che-chm.mapua.edu.ph/ (accessed on 28 January 2023))	47
	School of Civil, Environmental, and Geological Engineering (http://cege.mapua.edu.ph/ (accessed on 28 January 2023))	37
	School of Electrical, Electronics, and Computer Engineering (http://eece.mapua.edu.ph/ (accessed on 28 January 2023))	15
	School of Industrial Engineering and Engineering Management (http://ie-emg.mapua.edu.ph/ (accessed on 28 January 2023))	34
	School of Mechanical and Manufacturing Engineering (http://mme.mapua.edu.ph/ (accessed on 28 January 2023))	97

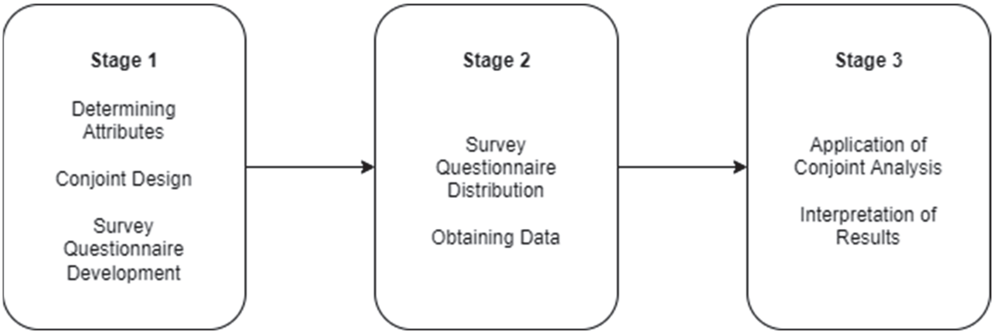

Figure 1. Overall conceptual framework.

2.2. Data Gathering

Survey questionnaires were distributed online among private institutions with recognized engineering programs in the Philippines. The study by Ong et al. [21] explained that conjoint analysis might consider a minimum of 150 respondents to have an acceptable output. Thus, Google Forms was used to obtain at least 200 responses from currently enrolled engineering students from different programs, from the first to the fifth year.

2.3. Conjoint Design

Conjoint analysis, specifically, orthogonal design conjoint analysis, is a tool utilized to assess consumer preference [21]. Compared to other choice-based modelling methods, conjoint analysis with orthogonal design generates the optimum output that represents and can present the optimum findings [22]. As commonly presented, choice-based analysis provides multiple combinations which attempt to measure all possible outcomes. With orthogonal design, manageable and optimum sets of combinations that participants can consider will be generated. This provides less strain for respondents, with only limited combinations, compared to an all combinations analysis.

Table 1 shows the attributes identified in this study for online learning delivery type. Six attributes (interaction, flexibility, communication, material, assessment, and proctored exam) were considered, along with their corresponding levels from various online literature. Furthermore, SPSS Statistics software was used to generate multiple combinations of attributes and levels, which is known as the stimulus in the conjoint analysis, as shown in Table 2.

The software also generated Pearson's r correlation, Kendall's tau, and Kendall's tau holdout values. The ideal values for Pearson's r correlation lie between 0.50 and 1.00, indicating that the variables are moderately highly correlated. From the study by Ong et al. [21], the acceptable value for Kendall's tau is equal to or greater than 0.70. The holdout value should be close to or equal to 1.00 but not exceed the cut-off, which indicates data overfitting.

The study by Ong et al. [21] found that the delivery type was one of the essential attributes of online learning. The preferred levels are a mix of synchronous and asynchronous classes, which are not considered in this study. However, the attributes considered in this research focused on classifying the delivery type preferred from the combinations generated. The first attribute was interaction, which, according to Moallem [23], is the heart of online learning education. The three levels are learner–instructor, learner–content, and learner–learner. A learner–instructor interaction is the communication between a student and an instructor. It emphasizes the importance of an instructor's role in defining the course's objectives, activities, and materials and providing feedback to students as they progress through the course. Learner–content interactions are how a student processes the information presented through the educational experience. This helps students achieve intellectual growth. Finally, the communications between students in a class are learner–learner interactions, which foster working together to learn from one another.

The second attribute in the list is flexibility. Soffer et al. [24] indicated that integrating flexibility in online courses allows students to learn according to their needs, and it often considers their complex lives. There are three levels for this attribute. Immediate refers to the same pace an instructor teaches and releases learning materials. Self-paced is when students can access all learning materials at their own convenient time. Lastly, scheduled is the option to access learning materials at any given time while an instructor conducts a real-time discussion on a set date. The third attribute to consider is communication. Xie et al. [25] mentioned that communication is a crucial knowledge transfer component between instructors and students. The levels for this attribute are the tools used: discussion board in the learning management system, live chat using messaging platforms such as MS Teams, and a consultation meeting with an instructor.

The fourth attribute is the material with which instructors educate their students, which is considered in the study by Muthuprasad et al. [20]. The first level for this attribute is when an instructor discusses a lesson in a pre-recorded video lecture. The second level is real-time lecture meetings on platforms such as Zoom or Google Meet, and the third is reading material with supplementary videos. An article by the University of Waterloo [9] found that in doing assessments, students should be given an element of choice for when they should complete deliverables for a course. For the fifth attribute, the considered levels are automatically available, wherein an instructor provides the seatwork or exam at any time, and adaptive release refers to students accessing content when initial conditions are met [26].

In the same study by Ong et al. [21] mentioned previously, the final requirement ranked first as the essential attribute that undergraduate industrial engineering students preferred was the multiple-choice exam as the chosen level. Moreover, because educational institutions value integrity among the students taking exams, the proctored exam is considered the sixth and last attribute, even for an online setup. The levels are whether students preferred to be proctored (yes) or not (no).

After encoding the attributes and their levels, the combinations of orthogonal design were generated (Appendix A). The SPSS software generated 16 combinations with two holdout cases, and having a holdout could be used to determine how consistent the responses were [21]. The results from the survey were used to determine the importance of each attribute, thus selecting the preferences of the engineering students for online learning delivery types. After instructions and item specifications with descriptions were provided, the generation of each combination for the preference analysis was prompted (Appendix B).

3. Results and Discussion

This study gathered 230 valid responses from currently enrolled undergraduate engineering students, collected from August–November 2022. The demographics, composed of 132 male and 98 female individuals, and the overall student profile of the respondents are presented in Table 2. A breakdown of student respondents is as follows: 51 students for the first year level, 56 students for the second year, 100 students for the third year, and the fourth and fifth years had 19 students and 4 students, respectively. In each school or department of the university, mechanical and manufacturing engineering had the highest numbers of respondents, garnering 97 responses, followed by chemical, biological and materials science engineering with 47, then civil, environmental and geological engineering with 37, and then industrial engineering and engineering management, which had 34. The least were from electrical, electronics, and computer engineering, which had 15 respondents.

3.1. Conjoint Study

A preliminary 40 respondents were gathered for the initial run. As shown in Table 3, the results met the acceptable values of Pearson's r, with 0.977, and Kendall's tau, with 0.874, and the holdout value was 1.00. Thus, the researchers proceeded with the conjoint study to analyze the preferences of engineering students on the delivery types for online learning. With the conjoint analysis output generated by the SPSS Statistics software, Table 4 shows the importance values of the six attributes.

Table 3. Correlations.

	Value	Significance
Pearson's r	0.977	0
Kendall's tau	0.874	0
Kendall's tau for holdout values	1.00	

Table 4. Importance values.

Attributes	Score	Rank
Interaction	43.798	1
Flexibility	20.198	2
Communication	11.636	4
Material	5.196	6
Assessment	5.891	5
Proctored exam	13.282	3

The interaction attribute had the highest average score of 43.798 among the six attributes. The second attribute in the ranking was flexibility, having a score of 20.198. The proctored exam had the third highest rank, with a score of 13.282. In fourth place, with 11.636, was communication, and in the last two places, assessment and material scored 5.891 and 5.196, respectively. For the levels of each attribute, Table 5 shows their utility scores. The utility is the subjective preference judgment of a person expressing a particular object's overall value or worth [27]. Therefore, the highest utility estimate is considered the preferred level of the students.

Table 5. Utilities.

Attributes	Levels	Utility Estimate	Standard Error
Interaction	Learner–instructor	0.358	0.034
	Learner–content	−0.043	0.04
	Learner–learner	−0.316	0.04
Flexibility	Immediate	−0.166	0.034
	Self-paced	0.145	0.04
	Scheduled	0.022	0.04
Communication	Discussion board	−0.106	0.034
	Live chat	0.073	0.04
	Consultation meeting	0.033	0.04
Material	Pre-recorded lecture	−0.001	0.034
	Real-time lecture meeting	0.041	0.04
	Reading materials and supplementary videos	−0.039	0.04
Assessment	Automatically available	0.045	0.026
	Adaptive release	−0.045	0.026
Proctored exam	Yes	−0.102	0.026
	No	0.102	0.026
(Constant)		4.727	0.031

For the highest-ranked attribute, the most preferred level was learner–instructor. It was evident from the study of Parker et al. [28] that college students performed on a stronger academic level when instructors posted frequently, responded to queries immediately, and integrated student feedback. The interpersonal interaction between a student (learner) and a teacher (instructor) encouraged students to commit to online courses. Hollister et al. [29]

mentioned online teaching in higher education wherein students who perceived teachers being actively involved in teaching were more effective at learning. Cranfield et al. [30] also concluded that the learner–instructor interaction is one of the significant predictors of student satisfaction in online learning. Hence, these findings emphasized the substantial role of learner–instructor interactions in student achievement and satisfaction. Contradicting the study of Ong et al. [21], it was seen that students more preferred self-paced learning compared to having an instructor around. However, this study was conducted during the early start of the COVID-19 pandemic, when all students and instructors were adjusting. It could be deduced that students had figured out that the learner–instructor interactions were relatively important and were still needed to foster learning.

The level for the second highest attribute that students considered for flexibility was self-paced. Waheed et al. [31] stated that flexibility was an element defining online learning. Students require a mechanism that encourages them to prioritize their studies, which usually takes the form of assignment deadlines and a set end date for the course, while still giving them the flexibility to schedule their work around them. This supports the study of Marciniak et al. [32], wherein students in self-paced learning showed excellent academic performance based on performance measures, including average scores on chapter tests and average performances on the final exam. The students were also more satisfied with self-paced as it gave them a sense of freedom in learning. However, the study by Mshayisa and Ivala [33] expounded on the idea that instructors at the back-end should be present for any concerns of the students in their self-paced learning. This means that teachers and instructors should not be totally unidentified during the flexibility of a learning experience.

In the third highest of the attributes, students preferred that online exams not be proctored. A study by Gumasing et al. [34] stated that students were concerned about the environmental and psychological factors of using e-proctoring tools while taking online exams as they imposed stress and anxiety among students during examinations. Alshammari et al. [35] stated that the implications of experiencing high test anxiety resulted in lower exam scores. In contradiction to the explanation, it could be supposed that when students have the proper time management skills, ability, and motivation, thorough effort and learning activities would still be accomplished in online learning [33].

Having a live chat through messaging applications with a professors was the students' preferred level of communication. The study by Sobaih [36] stated that students recognized live chat as most useful if an urgent response was needed, especially when taking assessments or doing assignments. When using a live chat as a tool for online academic help-seeking, blended learning students and online students were overwhelmingly satisfied. Most notably, students believed that teaching staff cared about assisting with their learning using live chats and they found it useful for real-time support. However, the appropriateness of LMS and online learning communication should be chosen according to the students' interests and to accommodate their general needs [37].

As for the assessment, students preferred it to be automatically available or accessible when professors released it on the learning management system (LMS) without initial conditions such as reading or watching additional lecture materials. It may also have fallen under the proctored exam attribute as students prioritized taking assessments on time. Regarding the materials for delivering course topics, real-time lecture meetings were the most preferred among the levels. Real-time lectures, also called synchronous sessions, are performed through video meetings. While technological difficulties are recognized to obstruct students from understanding lectures and discussions during synchronous sessions, Serdyukov [38] revealed that students appreciated synchronous sessions as they were given a platform to clarify complex topics to their professors.

From the generated stimuli using the SPSS software, the ranking was determined by substituting the values of the utility score of each level and summing it up for each combination. As seen in Table 6, the most favored stimulus of engineering students was combination #1, which was learner–instructor plus self-paced plus live chat plus pre-recorded lecture plus automatically available plus no. It was evident that among the top three combinations, the highest utility score of each attribute was present, thus proving a strong relationship between the observed and estimated preferences [39].

Table 6. Ranking of combinations.

Combination Number	Stimuli	Score	Ranking
1	Learner–instructor plus self-paced plus live chat plus pre-recorded lecture plus automatically available plus no	0.722	1
16	Learner–instructor plus scheduled plus consultation meeting plus real-time lecture meeting plus adaptive release plus no	0.511	2
15	Learner–instructor plus self-paced plus consultation meeting plus reading materials and supplementary videos plus automatically available plus yes	0.44	3
7	Learner–instructor plus scheduled plus live chat plus pre-recorded lecture plus adaptive release plus yes	0.305	4
3	Learner–instructor plus immediate plus discussion board plus real-time lecture meeting plus automatically available plus no	0.274	5
5	Learner–instructor plus immediate plus discussion board plus pre-recorded lecture plus adaptive release plus no	0.142	6
9	Learner–instructor plus immediate plus discussion board plus pre-recorded lecture plus automatically available plus yes	0.028	7
14	Learner–content plus immediate plus consultation meeting plus pre-recorded lecture plus automatically available plus no	−0.03	8
10	Learner–instructor plus immediate plus discussion board plus reading materials and supplementary videos plus adaptive release plus yes	−0.1	9
2	Learner–content plus self-paced plus discussion board plus real-time lecture meeting plus adaptive release plus yes	−0.11	10
4	Learner–content plus immediate plus live chat plus reading materials and supplementary videos plus no	−0.118	11
13	Learner–content plus scheduled plus discussion board plus pre-recorded lecture plus automatically available plus yes	−0.185	12
8	Learner–learner plus self-paced plus discussion board plus pre-recorded lecture plus adaptive release plus no	−0.221	13
11	Learner–learner plus scheduled plus discussion board plus reading materials and supplementary videos plus automatically available plus no	−0.292	14
17	Learner–learner plus self-paced plus discussion board plus reading materials and supplementary videos plus automatically available plus yes	−0.373	15
6	Learner–learner plus immediate plus live chat plus real-time lecture meeting plus automatically available plus yes	−0.425	16
12	Learner–learner plus immediate plus consultation meeting plus pre-recorded lecture plus adaptive release plus yes	−0.597	17
18	Learner–learner plus immediate plus discussion board plus real-time lecture meeting plus adaptive release plus yes	−0.694	18

The levels from the preferred combination were learner–instructor, live chat, real-time lecture meetings, and automatically available, with a focus on the synchronous online learning mode. In contrast, the self-paced level focused on the asynchronous mode. In general, the combination fit the blended delivery type for online learning. Blended online learning is defined as the completely online, simultaneous, and complementary integration and implementation of an asynchronous mode, partially system-managed, partially faculty-led learning environment (i.e., a course management system (CMS)) and a synchronous mode, partially system-managed, partially faculty-led learning environment (i.e., a virtual classroom environment) [37]. Blended online learning, which can also be referred to as "Bichronous" online learning, as defined by Marfuah et al. [40], is the blending of synchronous and asynchronous online learning modes. In bichoronous sessions, students can engage anytime and anywhere during the asynchronous portion of the course and participate in real-time activities during the synchronous sessions.

The blended mode of online learning delivery type does not only benefit student, it also benefits instructors and professors. According to Coman et al. [41], those who resisted online instruction before learning new pedagogical techniques in delivering lessons will be more at ease modifying their Powerpoint presentations during real-time lecture meetings. While preserving the LMS benefits in managing assignments and grades and encouraging the critical thinking associated with asynchronous discussion, blended online learning may also address those limitations for instructors.

Moreover, a mitigation plan, shown in Table 7, for implementing a blended mode delivery type shows the possible risks in the following three categories: student experience, technological issues, and course concerns. Based on the study by Ranadewa et al. [42], personal commitments can affect student participation in online learning. This is seen as an identified risk during synchronous sessions. Scenarios such as caring for a family member will split a student's attention and may affect their engagement in the lesson taught. Thus, posting recorded lectures in the LMS, such as Blackboard, canvas, etc., can help students review their lesson again.

Table 7. Mitigation plan.

Category	Identified Risk	Mitigation Plan
Student experience	Synchronous sessions may conflict with duties at home	Recording of the real-time lecture should be posted after the meeting
Technological issues	Unstable internet connection	Lenient deadlines for assignments
Course concerns	Possibility of cheating during non-proctored exams	Different sets of questions for exams or the use of a locked-down browser

Cahyani et al. [43] mentioned that internet connections and network issues are challenges in blended online learning. For example, the lagging of internet connections provided students with misunderstandings among faculty instructions related to coursework. Second, students may not totally comprehend the lesson proper due to inefficient connections, leading to lagging or choppy lessons that students have difficulties in comprehending. Others may also relate to assessments in class held synchronously, big-data-aligned learning management systems, technology tools, and communications, in general. The participation of students would therefore be hindered by slow internet connections. Thus, faculty members should be lenient towards deadlines and may impose policies on late submissions so that students will not take advantage of them and use them as excuses. Lastly, because students prefer that online exams not be proctored, using a locked-down browser or an application that disables students from opening any tab on the browser will tighten security during an examination. In an attempt to try to mitigate academic integrity, the current set-up being practiced is to have cameras behind and in front of the students taking the assessment synchronously. This manner of proctoring has been seen to be time-consuming to set-up, require larger internet data, and hinder students in quickly analyzing questions due to system loading. Instructors may also create different questions or sets of exams so that students cannot discuss answers among themselves.

3.2. Online Learning at Mapua University as a Benchmark

In the academic year 2021–2022, Mapua University offered two modalities for online learning. The first was UOx, which is a fully online learning delivered asynchronously. This state of learning modality provides students the option to take into consideration the lessons, activity, and performance any time of the semester. The other modality was blended learning. The blended learning modality adopted was a mix of bichronous (limited face-to-face meetings and online meetings assigned by the instructor) or synchronous online sessions. However, the face-to-face classes under blended learning were limited to particular courses per program and depended on the government's policy, which is why most classes are still held online in the Philippines [43]. The learning management system (LMS) used by the university was Cardinal Edge, a Mapua LMS powered by Blackboard Learn. During the first few months when online classes were implemented, Blackboard Collaborate was used to conduct synchronous sessions until Zoom was discovered as a more effective and user-friendly application to conduct real-time lecture meetings and monitor students during online examinations. However, some professors required another application to be used for the students' screens to be shared while taking tests. Besides the online learning activities (OLA) and module exams, some courses required a research paper as an end-of-term project and completion of Coursera courses. Coursera courses are utilized in different applicable courses in an attempt to provide coherent and related academic tasks, offer more lessons from a different perspective and approach, and provide students with other learning materials that are related to the course being taken. The current grading system being implemented is a modular system wherein the course is divided into two to three modules. Every module has a corresponding grade computed every 3–4 weeks. By the end of the term, the average of all the modules will be the student's final grade.

3.3. Practical Implications and Suggestions

This study revealed engineering students' preferences for the delivery types of online learning. As universities continue to offer fully online courses, professors and administrators of higher education institutions may consider this study to improve the online learning experience of their students as the information given supports the need to implement a blended mode as the online learning delivery type. Since limited face-to-face instruction is now being implemented, administrators must know whether students prefer to attend class physically. Some students have moved back to provinces and overseas. In contrast, others may be anxious about contracting COVID-19 when frequently exposed outside their homes. They should also study which courses should be implemented as bichronous or synchronous delivery types depending on the nature of the course, if it is purely theoretical, etc.

For blended online learning, instructors must always upload a copy of the video recording of a synchronous class for students who cannot attend. Synchronous sessions can be held once per week and during exams. It is also preferable that all lecture materials to be discussed be uploaded at the start of the term. The submission of online learning activities should at least have a one-week deadline to avoid an overload of requirements.

3.4. Limitations of the Study and Future Research

Although this study had a relatively large sample size, it was limited to undergraduate students taking engineering courses. The students who answered the survey were also enrolled in the blended learning modalities offered by the universities. The perceptions of instructors and students enrolled under different learning modalities and their effectiveness should also be addressed. This is a recommendation for future research to consider. Especially now that we are nearing the end of the COVID-19 pandemic, the traditional face-to-face learning modality is being implemented. Thus, future studies may want to consider an analysis of the behavioral intentions of students. On the other hand, analyses such as behavioral intentions for future enrollment in the different modalities and comparisons thereof may be conducted to enhance the implications, policies, and strategies of universities. For a more comprehensive analysis, clustering techniques may be considered to segregate the demographics of students taking up the different modalities. Lastly, machine learning algorithms or multivariate analysis may be applied, aligning with the variables considered in this study to assess the impacts among the different aspects of behavioral, cognitive, and even physical latent variables for a holistic measurement.

4. Conclusions

Two years have passed since the implementation of online learning globally because of the COVID-19 pandemic. However, students and teachers are still adjusting to the online learning environment, especially in the Philippines. As studies prove the correlation between student satisfaction and academic achievement, this study focused on the delivery type of online learning that students would prefer. The researchers generated 18 combinations of stimuli and performed conjoint analysis using the SPSS Statistics software based on the responses of the engineering students. The values of Pearson's r and Kendall's tau proved the validity of the responses as the correlation between the observed and estimated preferences is within the accepted range. The results led to defining the favored combination as blended mode where students interact with an instructor through real-time lecture meetings, ask for clarifications in live chat via messaging applications, are able to answer assessments with no surveillance during an exam, and are given the opportunity to access all learning materials at any time. This merging of the synchronous and asynchronous modes in online learning provides a learner with options for managing their time efficiently to perform better academically and to perform their responsibilities at home.

From the findings, it is suggested that professors and administrators of higher education institutions may consider this study to improve the online learning experience of their students as the information given supports the need to implement a blended mode as the online learning delivery type. With the current implementation of several learning modalities in the Philippines for students to choose from, universities may opt to consider and promote the attribute combinations found in this study for assurance of student satisfaction and motivation in continuous learning. This way, the modalities reflect towards students' academic motivation and determination in academic achievement, relating to the discussions made by related studies [21,34,44,45]. Similarly, the incident of providing the appropriate platform for both blended and fully online learning may enhance student satisfaction in an online learning engagement. For blended online learning, instructors must always upload a copy of the video recording of a synchronous class for students who cannot attend. Synchronous sessions can be held once per week and during exams. It is also preferable that all lecture materials to be discussed be uploaded at the start of the term. The submission of online learning activities should at least have a one-week deadline to avoid an overload of requirements.

Future studies may expand on this study by surveying numerous universities and including all undergraduate courses. Comparison and contrast may provide further insights and determinations, and future studies may incorporate these findings to provide a more holistic and generalized marketing and academic strategy. Researchers may also incorporate a student's learning style in determining their relationship to their online learning delivery type preference. Lastly, several approaches towards behavioral studies, clustering for the determination of similar characteristics and demographic profiles, and even multivariate and algorithm tools may be used for analysis.

Author Contributions: Conceptualization, J.S.G.Y. and E.M.D.C.; methodology, J.S.G.Y. and E.M.D.C.; software, J.S.G.Y. and E.M.D.C.; validation, J.S.G.Y., E.M.D.C. and A.K.S.O.; formal analysis, J.S.G.Y., E.M.D.C. and A.K.S.O.; investigation, J.S.G.Y. and E.M.D.C.; resources, J.S.G.Y. and E.M.D.C.; data curation, J.S.G.Y. and E.M.D.C.; writing—original draft preparation, J.S.G.Y. and E.M.D.C.; writing—review and editing, J.S.G.Y., E.M.D.C. and A.K.S.O.; visualization, J.S.G.Y., E.M.D.C. and A.K.S.O.; supervision, J.S.G.Y. and A.K.S.O.; project administration, J.S.G.Y. and A.K.S.O.; funding acquisition, J.S.G.Y. and A.K.S.O. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in this study (FM-RC-23-02-06).

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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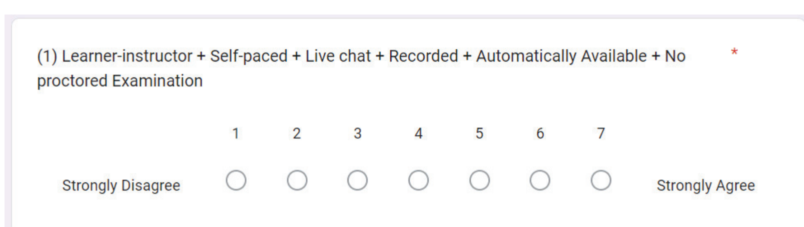
Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Generated Stimuli

Interaction	Flexibility	Communication	Method	Assessment	Proctored Exam
Learner–instructor	Self-paced	Live chat	Recorded	Automatically available	No
Learner–content	Self-paced	Discussion board	Real-time lecture	Adaptive release	Yes
Learner–instructor	Immediate	Discussion board	Real-time lecture meeting	Automatically available	No
Learner–content	Immediate	Live chat	Reading materials and supplementary videos	Adaptive release	No
Learner–instructor	Immediate	Discussion board	Pre-recorded lecture	Adaptive release	No
Learner–learner	Immediate	Live chat	Real-time lecture meeting	Automatically available	Yes
Learner–instructor	Scheduled	Live chat	Pre-recorded lecture	Adaptive release	Yes
Learner–learner	Self-paced	Discussion board	Pre-recorded lecture	Adaptive release	No
Learner–instructor	Immediate	Discussion board	Pre-recorded lecture	Automatically available	Yes
Learner–instructor	Immediate	Discussion board	Reading materials and supplementary videos	Adaptive release	Yes
Learner–learner	Scheduled	Discussion board	Reading materials and supplementary videos	Automatically available	No
Learner–learner	Immediate	Consultation meeting	Pre-recorded lecture	Adaptive release	Yes
Learner–content	Scheduled	Discussion board	Pre-recorded lecture	Automatically available	Yes
Learner–content	Immediate	Consultation meeting	Pre-recorded lecture	Automatically available	No
Learner–instructor	Self-paced	Consultation meeting	Reading materials and supplementary videos	Automatically available	Yes
Learner–instructor	Scheduled	Consultation meeting	Real-time lecture meeting	Adaptive release	No
Learner–learner	Self-paced	Discussion board	Reading materials and supplementary videos	Automatically available	Yes
Learner–learner	Immediate	Discussion board	Real-time lecture meeting	Adaptive release	Yes

Appendix B. Sample Survey Generation


(1) Learner-instructor + Self-paced + Live chat + Recorded + Automatically Available + No proctored Examination *

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

Note: * dictates the required question to be addressed.

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Article

A Multidimensional Evaluation of Technology-Enabled Assessment Methods during Online Education in Developing Countries

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Abstract: Humanity has faced unprecedented chaos in the education sector due to the inevitable sudden adoption of online mode of learning during the pandemic. The complexities associated with technology-enabled learning and assessment have different connotations in developing countries due to a lack of infrastructure and awareness. Such countries can switch over to an online mode of education more frequently in the future due to highly volatile local political and cultural situations on top of the pandemic. This study evaluates the complexities associated with technology-enabled online assessment methods in Pakistan. Technology readiness and performance for the learning assessment of students are appraised through approaching approximately one thousand students from more than one hundred public and private sector engineering universities. A screened list of assessment alternatives and their influencing factors are then prioritized using the multi-actor multi-criteria analysis (MAMCA) by considering the perceptions of national policymakers, faculty members and students. The aggregate results reveal that, among the influencing factors, 'mental health' received the highest weightage, and stakeholders are indifferent to associated costs despite financial challenges. Automated MCQs secured the top position in the ranking list. Sensitivity analysis incorporates some disagreements among the stakeholders, which makes this study highly beneficial for policy modeling.

Keywords: online learning and assessment; multi-actor multi-criteria analysis (MAMCA); technology readiness; automated assessment methods

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1. Introduction

The unprecedented outbreak of COVID-19 posed extraordinary challenges to higher education institutions in their teaching and learning activities. Apart from ensuring the quality of online education, the major challenge due to the pandemic was assessing the students remotely. Since there was no clear policy or guidelines in most higher education institutions, either for online teaching or assessment methodology, the institutions felt handicapped. The students pursuing professional degrees were the ones who suffered the most since the delay in the educational process resulted in a delay to start their careers [1].

Universities had to increase their productivity and efficiency by making use of technology and virtually increasing their reach to students [2]. Consequently, most higher education institutions now offer online courses and have adopted modern techniques [3,4]. The new techniques are based on the E-learning methodology, which includes the use of online learning portals, video conferencing, streaming on social media, such as WhatsApp, Telegram and mobile apps, such as Zoom, Google Meet and Microsoft Teams [5,6].

The inclusion of artificial-intelligence-based learning themes has changed the traditional way of education to the modern ways of learning [3,6,7]. These circumstances have, therefore, attracted many researchers and policymakers to evaluate these new technologies under the context of their acceptance among societies [8].

Online learning and assessment had a different connotation in developing countries [6]. It badly affected every facet of life, most prominently the education sector, where the educational institutions were the first ones to be closed [3]. Apart from the usual challenges in the online mode of learning, developing countries had much greater issues. Developed countries had been partially using the online mode of teaching for a long time, however, developing countries mostly adopted it after the pandemic and, therefore, had to face plenty of hurdles in the implementation process [6,9].

There were several concerns, such as students coming from remote areas with no internet connections; students coming from poor families attempting to learn online while living in only two rooms with five to six family members; non-availability of educational tools, such as laptops, mobile phones and tablets [9] (prerequisites for online education), as the parents could not afford to provide these for their every school-going child. All this further amplified the severity of the pandemic for educational systems in developing countries.

Most of the studies on online education reported in the literature provide instances from developed countries. Models that have been used in some of the past studies on online learning and assessment are summarized in Figure 1. The presented studies evaluate the acceptance and optimization of online education using different techniques.

TAM and DM Models have been successfully utilized for efficiency measurement of the online education system. TAM [10] provides various solutions based on the results, such as e-monitoring [11], to be the optimal solution. Some of the studies are from the perspective of COVID-19 [12,13], and others compare online education with the conventional education system [14]. Some of the studies compared different demographics, such as gender [4], for the evaluation of online education quality.

One important challenge associated with online education is how readily different cultures adopt the technology [9]. Research on technology acceptance has yielded important insights into the complexities of how and why people choose to embrace or reject technology, as well as the rate at which that acceptance or rejection occurs [15]. Students and instructors in both developed and developing nations faced technological challenges including the lack of technical skill sets and economic restrictions while implementing virtual classroom environments [12,13,16,17]. Figure 1 also highlights the research studies that focused on TAM and its factors. TAM gives insight into some of the factors that determine the user's acceptance behavior of new technology. Those factors include Facilitating Conditions, Attitude, Computer Efficacy and Technological Anxiety [18–21].

Another important aspect is to measure the effectiveness of an online learning system as compared with traditional learning. There is a need to develop an efficient system for the measurement of the quality of online education. The DM model, often known as the IS (Information Systems) success model, has received a great deal of attention from information system experts. It has been used in previous studies by researchers for assessing the success of various systems [22–25]. In the Information System Success model, the studies emphasized six dimensions, including Information Quality, System Quality, System Use, User Satisfaction and Organizational Impact [2,22,26–29].

To concurrently address the issues of technology acceptance and effectiveness, both the TAM and DM models are utilized in the first phase of the current research, which is elaborated in the next section.

After the implementation of an effective online learning system, one of the major challenges is the assessment of online learning, specifically for developing countries, since the education ministries have yet to establish strategies that address key issues about exams including integrity, accuracy, convenience, etc. In addition to the traditional evaluation techniques, such as projects and viva, the need of online education has compelled the policymakers to adopt non-traditional evaluation alternatives, including individual projects, MCQs within a time window, multiple version exams, close book, participation-based assessment, e-proctoring [30], open-book exam, open-book exam (slot within a timed window), open-book exam (timed window), research paper, annotated anthology, bibliography, literature review, reports, memos, reflection paper, class presentation, one-on-one oral exam and audio-visual presentation [31–35], as shown in Figure 1.

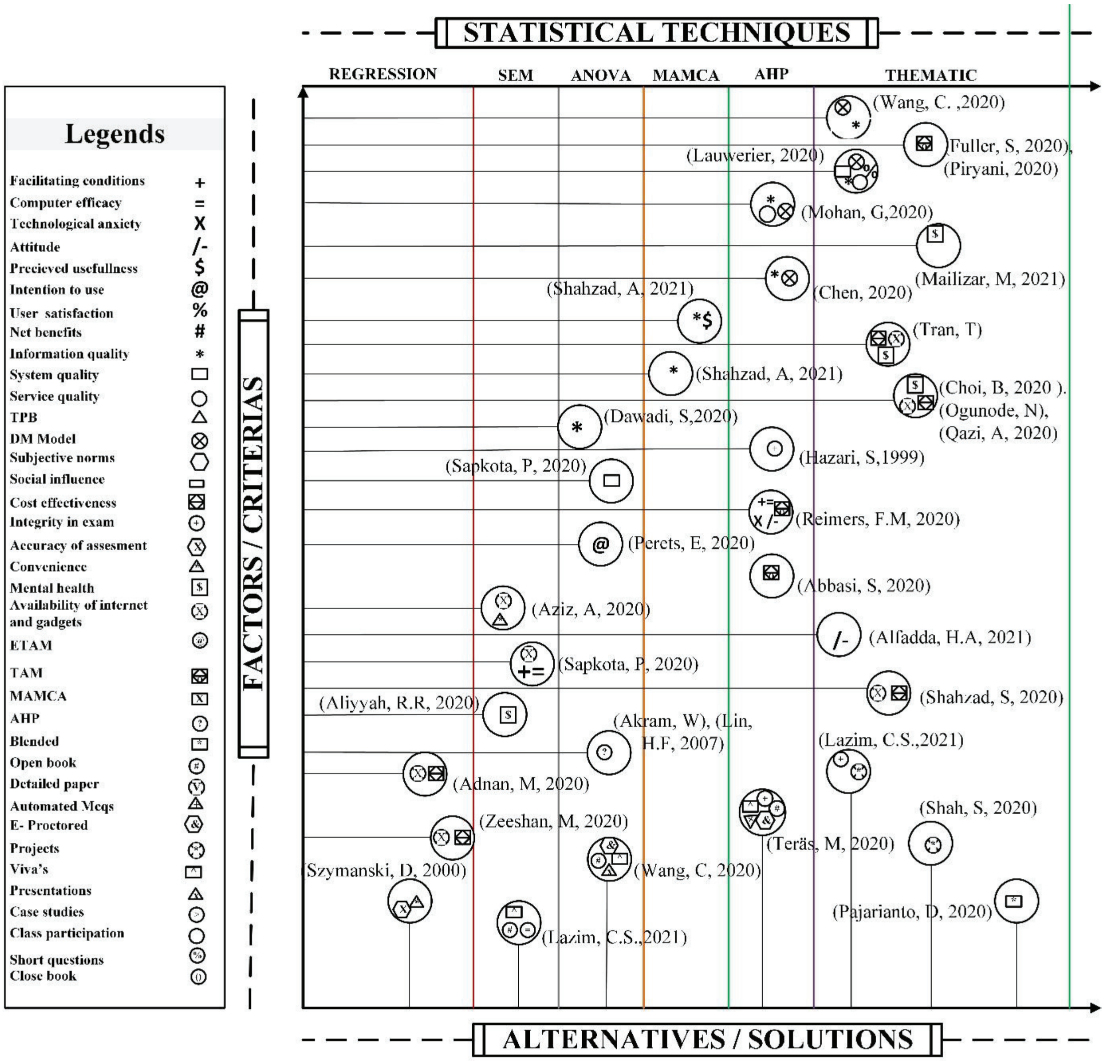


Figure 1. Overview of recent research on factors, alternatives and analysis techniques in online education.

When deciding to select an optimal assessment policy for educational institutes in developing countries, it is requisite to rationally evaluate the available alternatives and their influencing criteria under the cultural and social context of these countries. It can be ensured by considering all the affecting parameters and considering the opinion of stakeholders. Tools from the domain of multi-criteria decision-making (MCDM) can be utilized for these kinds of problems.

It is because of this multidimensional nature of the MCDM methodologies that they are being used in some latest studies on the evaluation of online education. A few such instances include prioritization of criteria for e-learning systems using Fuzzy-MCDM [36], evaluating the adequacy of online systems [37], satisfaction assessment of online education [38] and selection of universities in the COVID-19 [39], etc. An extended form of MCDM is the Multi-actor Multi-criteria Analysis (MAMCA), which ensures the inclusion of different actors on top of the alternatives and criteria.

It can be inferred from the literature that researchers have not yet focused on evaluating the technology-enabled online learning and assessment in developing countries where the cultural and social circumstances make things much more complex and multifaceted than in the developed world.

There is a need to study the technology readiness/effectiveness and investigate the factors that can have an impact on online assessment methods. This can be ensured only by taking a broader spectrum of influencing criteria and involving the opinion of all concerned stakeholders. Moreover, previous studies have discussed some other aspects of online education; however, the issue of online exam conduct is only rarely addressed.

This study intends to propose a policy recommendation framework based on measuring the technology readiness and effectiveness and prioritizing the online learning assessment methods using MAMCA. This has been done in two phases. The first phase includes measuring the technology readiness and effectiveness using TAM and DM models as it is an inevitable pre-requite for technology-enabled online assessment. The second phase explores and prioritizes the online assessment methods and their influencing criteria using MAMCA. These two phases are elaborated in the next section of the paper, which also includes modeling of the problem. Developed models are solved using the concerned software in the Results and Discussions section. Section three also includes a sensitivity analysis that gauges the robustness of models.

2. Materials and Methods

In this section, two phases of the adopted research methodology are elaborated. The first phase applies the hybrid TAM and DM models to evaluate if the students of developing countries are ready to accept and efficiently utilize the technology during online education without compromising the learning quality. In the second phase, the factors and alternatives for technology-enabled online assessment are prioritized using the multi-actor multi-criteria analysis (MAMCA) by taking all stakeholders on board.

2.1. Phase I: Evaluation of Technology-Enabled Online Learning Using TAM and DM

In this phase of research, the TAM and DM models are merged to evaluate whether the students have efficiently accepted the technology-enabled online learning without compromising the learning quality. The factors adopted from the TAM and DM models are summarized in Figure 2.

Twelve hypotheses are built using variables from TAM and DM that have been incorporated. An influence on the assessment of technology-enabled online learning is hypothesized for each factor. From a survey of the literature and opinion of expert's Technology-enabled online education is thought to be very impactful in terms of facilitating conditions, attitude, computer efficacy, technological anxiety and all the other DM model constructs [4,18].

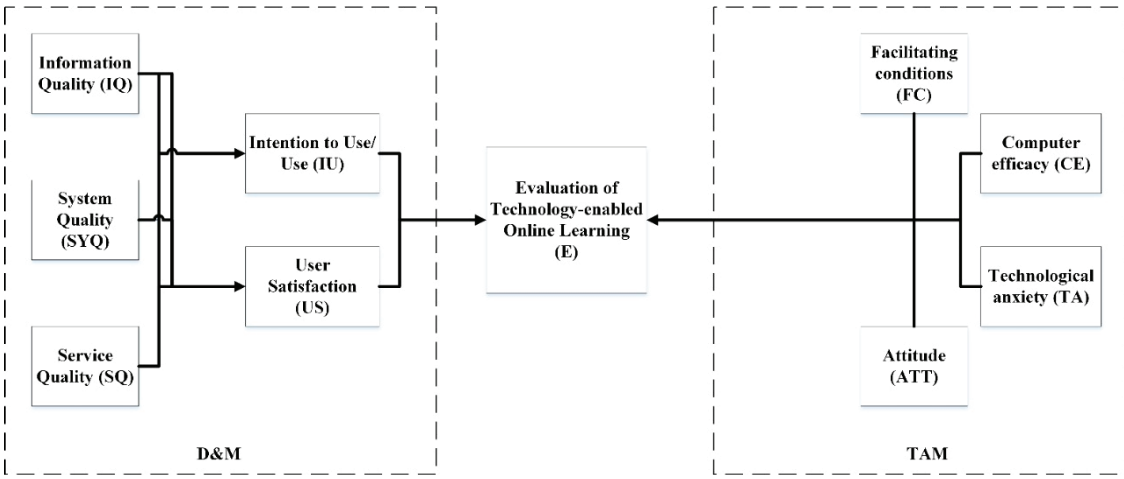


Figure 2. Merging the TAM and DM for technology-enabled online education.

Questionnaire Development and Participants of the Study

The Questionnaire developed for this study consisted of three (03) Sections. The first section specified the demographic information while the rest of the two sections were for questions regarding all hypotheses. The Questionnaire consisted of Likert-scale questions ranging from 1 to 5, with 1 representing "strongly disagree" and 5 representing "strongly agree". The data was collected by adopting an online survey methodology to maximize the response rate [40]. The survey was conducted through google forms using online study groups and other social media platforms.

The designed questionnaire was circulated among the students at different institutes of Pakistan (round 138 institutes) with diversified demographics, following a convenience sampling technique via email and by using social media, such as WhatsApp and Facebook. A total of 837 responses were obtained. The targeted participants are from public and private sector engineering universities' enrolled in undergraduate and graduate programs. A questionnaire has been filled with a nearly equal ratio of male and female participants to make the study free from gender bias.

As the research aims to investigate the factors that impact online learning, the TAM questionnaire has been modified in this study to match the current requirements. The predefined model of TAM has a list of constructs; however, only four of them are screened for this analysis. Based on these constructs, twelve hypotheses have been made to measure the significance of each construct with technology-enabled online learning. Some of the built TAM hypothesis are elaborated here as examples.

Technological anxiety is the major construct of TAM. As the current study is from the perspective of students, it is important to assess their anxiety toward technology while implementing online learning methods [4]. The stated hypothesis will assume that Technological Anxiety has an impact on the evaluation of technology-enabled online learning.

Attitude has been the significant construct of TAM. The term "attitude" refers to a person's inclination to react positively or negatively to an experience. Refs. [41,42] found that attitude is a determining element of behavioral intention toward e-learning usage in previous research on e-learning adoption.

Refs. [43,44] revealed that attitude is a dominating element in influencing behavioral intention. Thus, this hypothesis proposes that Attitude has an impact on the evaluation of technology-enabled online learning. The degree to which a person feels that an organizational and technological infrastructure exists to enable the usage of the system is referred to as Facilitating Conditions. While conducting online education, gadgets have a crucial role. The network (e.g., wireless and satellite) and technology (e.g., computers, laptops and smartphones) are utilized to determine the type of online learning. Courses, modules and smaller learning units [45] are all examples of online learning. The notion is that there is sufficient infrastructure to facilitate the usage of technology. Based on the above discussion, we propose that Computer Efficacy has an impact on the evaluation of technology-enabled online learning.

Similarly, constructs that come from the DM model are predefined, and the hypothesis is made as per the required relation to measure the technology-enabled online learning, especially from a student perspective [4]. For quantitative data analysis, the use of Structural Equation Modelling [46] has been adopted as per recommended practices [47]. It entails a thorough study of the data and verifies the model's validity.

Detailed steps of the SEM are presented in the form of a flow diagram in Figure 3. Table 1 shows the hypotheses that were created as a part of the DM and TAM Models. The technology acceptance model (TAM) was used to construct the attitude (ATT), computer efficacy (CE), enabling conditions and technology anxiety. The dependent factor evaluation of technology-enabled online learning, or "E," must relate to each of the elements. This will demonstrate how attitude and the assessment of technologically enhanced online learning are related. Similarly, all DM components are related to the dependent variable "E".

Table 1. Developed research hypotheses.

Factors	Abb	Relationship	Hypothesis
Attitude	ATT	ATT -> E	H1: Attitude has an impact on the evaluation of technology-enabled online learning.
Computer Efficacy	CE	CE -> E	H2: Computer Efficacy has an impact on the evaluation of technology-enabled online learning.
Facilitating Conditions	FC	FC -> E	H3: Facilitating Conditions have an impact on the evaluation of technology-enabled online learning.
Information Quality	IQ	IQ -> IU	H4: Information Quality has an impact on Intention to Use.
		IQ -> US	H5: Information Quality has an impact on User Satisfaction.
Intention to Use	IU	IU -> E	H6: Intention to Use has an impact on the evaluation of technology-enabled online learning.
Service Quality	SQ	SQ -> IU	H7: Service Quality has an impact on Intention to Use.
		SQ -> US	H8: Service Quality has an impact on User Satisfaction.
System Quality	SYQ	SYQ -> IU	H9: System Quality has an impact on Intention to Use.
		SYQ -> US	H10: System Quality has an impact on User Satisfaction.
Technological Anxiety	TA	TA -> E	H11: Technological Anxiety has an impact on the evaluation of technology-enabled online learning.
User Satisfaction	US	US -> E	H12: User Satisfaction has an impact on the evaluation of technology-enabled online learning.

2.2. Phase II: Prioritization of Technology-Enabled Online Assessment Methodologies Using Multi-Actor Multi-Criteria Analysis (MAMCA)

In the second phase of the study, the technology-enabled assessment methodologies are prioritized using Multi-Actor Multi-Criteria Analysis (MAMCA) considering the opinions of three stakeholders including students, faculty members and policymaker persons from the education ministry. There were a total of 35 to 40 students who attended a physical meeting conducted for this study.

Pairwise comparisons required for the Analytic Hierarchy Process were performed in the respective software during the same meeting interactively. Faculty members approached for this study were mostly deans, chairs and professors from various engineering institutes. Representatives of the third stakeholders were from HEC (Higher Education Commission) and the ministry of education. All of them had more than 10 years of professional experience in the field.

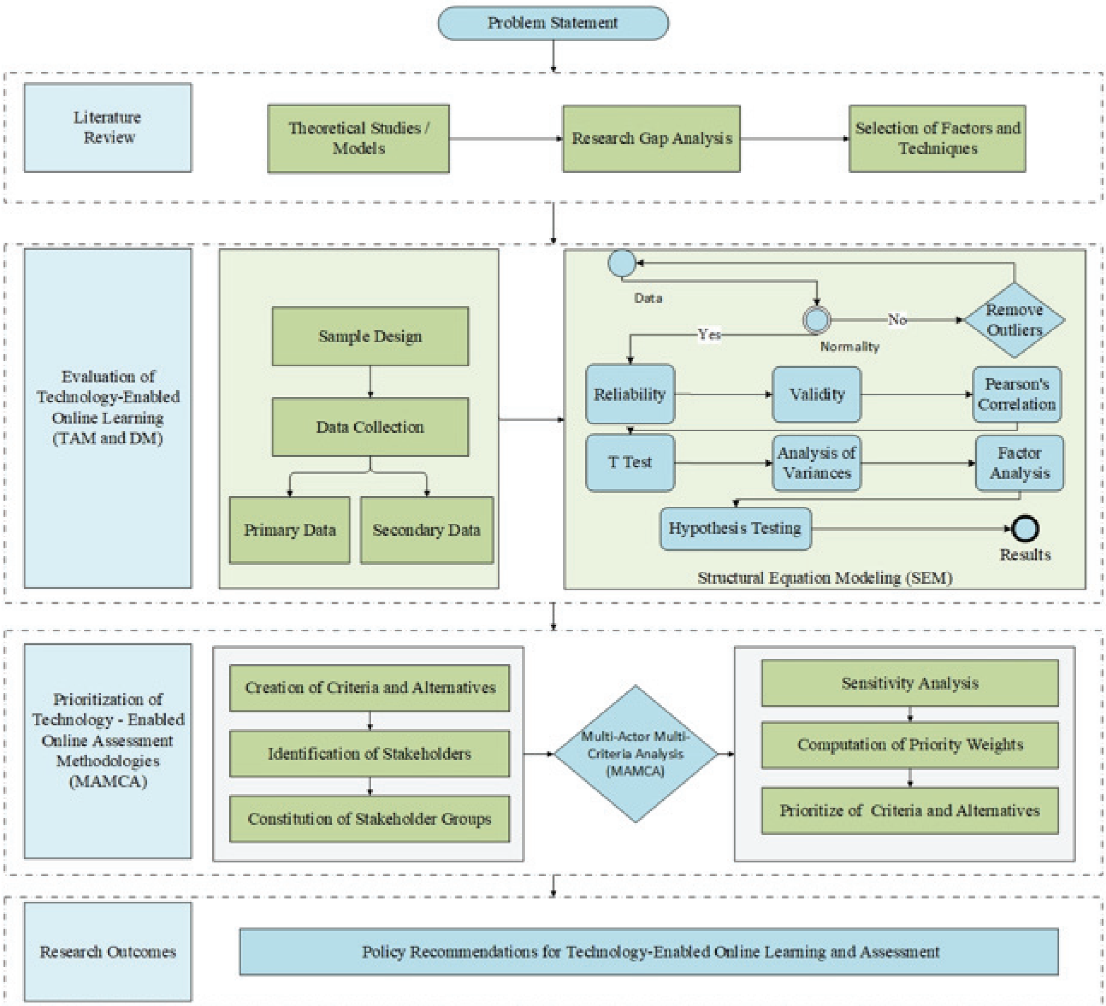


Figure 3. Research methodology.

The Analytical Hierarchy Process (AHP) is utilized to model the MAMCA for each stakeholder as well as the overall results [48–50]. With the MAMCA, one can explicitly take the objectives of complex projects into account and come to a good overview of the advantages and disadvantages of different options. Analytic Hierarchy Process (AHP) is applied under the perspectives of different stakeholders and the aggregate priority weights and rankings are eventually computed. The results are presented in the form of multiple actors (stakeholders) and as a whole [51].

The pairwise comparison matrix results in a square matrix of S_{nxn} as shown in Equation (1). The element s_{ij} represents the relative importance of criterion i with respect to criterion j. In the matrix, $s_{ij} = 1$ only when i = j.

$$S = \begin{bmatrix} 1 & s_{12} & s_{13} & \cdots & s_{1n} \\ \frac{1}{s_{12}} & 1 & s_{23} & \cdots & s_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \frac{1}{s_{1n}} & \frac{1}{s_{2n}} & \frac{1}{s_{3n}} & \cdots & 1 \end{bmatrix} \tag{1}$$

Normalized form of the scores presented in Equation (1) are given in Equation (2).

$$c_{ij} = (s_{ij}) / (\sum_{j=1}^{n} s_{ij}) \tag{2}$$

for i and j = 1, 2, 3, . . . , n.

After normalization, the weight vector 'w' of decision-makers is presented (Equation (3)), which is also referred to as the priority vector of the decision-maker.

$$w_i = \left(\sum_{i=1}^{n} c_{ij} \right) / (n) \tag{3}$$

For i and j = 1, 2, 3, . . . , n.

All Alternatives and Criteria are based on the elements considered in determining the impact of online learning. A 9-point Likert scale questionnaire was created to collect responses from all stakeholders, including students, teachers and senior members of HEC. Face-to-face meetings, as well as online sessions on Zoom and Microsoft teams, were used to collect data. This procedure was done using the AHP Software for Collaborative Decision-Making Solution to assign weights to all proposed Criteria and Alternatives for conducting online exams.

2.3. Linkage of the Two Phases

While the main emphasis of this research is on reducing the complexities associated with the prioritization of technology-enabled assessment methods, it has been first evaluated whether the students are ready to accept the respective technology effectively. We enter into the second phase, once the acceptance and effectiveness of online education is appraised. Since the main focus of this paper is on the prioritization of assessment alternatives, we excluded the other two stakeholders during the first phase. We assume that faculty members of engineering universities are either already comfortable with the technology or will be trained to handle this new technology as a part of their job.

3. Results and Discussion

In this section, results obtained from the two phases of research are presented in two subsections.

3.1. Evaluation of Technology-Enabled Online Learning

This section presents the results obtained from the hybrid TAM and DM models, which encompass the performance and acceptance of technology-enabled online education. The designed questionnaire was circulated among the students of more than one hundred engineering institutions in Pakistan with diversified demographics, following convenience sampling technique. A total of 837 responses were formally recorded. Three records were deleted, being outliers. Demographic details with the frequency of the records are shown in Table 2.

Table 2. Demographic details of the respondents.

Variables	Indicators	Frequency	Percentage%
Gender	Female	262	31.3
	Male	575	68.7
Institute type	Public	681	81.4
	Private	156	18.6

The observed data is normally distributed, as the skewness and kurtosis values of the variables are within the range of ±1.96 and ±1, respectively. Following the confirmation of data normality, some reliability and validity tests of the suggested model were determined.

Table 3 includes the constructs of the current research with different indicators/items, depending upon the required information. Constructs can have two items/indicators if the required dimension of the construct is fully accomplished [52]. Every item has different loading values, but all of the loading values are greater than 0.50, which means that the items are significant to make each construct [53]. Structural equation modeling [46] was used to analyze the results quantitatively.

Table 3. SEM outputs.

Constructs	Indicators	Loadings (>0.50)	Cronbach's Alpha (0.7–0.88)	R Square	Composite Reliability (>0.82)	Average Variance Extracted (>0.50)
ATT	ATT1	0.842	0.72		0.82	0.54
	ATT2	0.578				
	ATT3	0.647				
	ATT4	0.837				
TA	TA1	0.909	0.7		0.86	0.75
	TA2	0.823				
CE	CE1	0.912	0.82		0.92	0.85
	CE2	0.929				
FC	FC1	0.892	0.7		0.87	0.77
	FC2	0.861				
IQ	IQ1	0.860	0.73		0.88	0.78
	IQ2	0.910				
SYQ	SYQ1	0.898	0.7		0.87	0.76
	SYQ2	0.850				
SQ	SQ1	0.849	0.83		0.9	0.74
	SQ2	0.885				
	SQ3	0.854				
IU	IU1	0.865	0.72	0.291	0.88	0.78
	IU2	0.900				
US	US1	0.914	0.88	0.729	0.92	0.74
	US2	0.838				
	US3	0.916				
	US4	0.766				
E	E1	0.886	0.85	0.879	0.9	0.69
	E2	0.781				
	E3	0.820				
	E4	0.828				

The consistency and reliability of the records were checked using a reliability test that measured the dependability of each construct using loading values for the items [53]. A Cronbach's alpha value greater than 0.7 shows that the sample is highly reliable [54]. From Table 3 the values of Cronbach's alpha (0.7–0.88) indicate a significantly high internal consistency of the data. User satisfaction has the highest Cronbach's Alpha value (0.88), which means that it has significantly high internal consistency among all the constructs.

A convergent validity test was conducted to measure the accuracy of the research instrument. It determined via three measures viz. loadings, composite reliability (CR) and average variance extracted (AVE). The values of the item loadings, CR and AVE must be greater than 0.5, 0.7 and 0.5, respectively [53]). The average variance extracted (AVE) is a measure of how much variation a concept captures compared to how much variance is attributable to measurement error. The obtained values of CR, AVE and items loading are above the threshold point, which confirms convergent validity. All the indicators have item loading values greater than 0.05, CR value greater than 0.82 and AVE greater than 0.50 means that all the constructs are accurate for this predictive model. R-squared indicates the amount of shared variation between two or more variables.

The R-squared values for both independent variables is 0.291 and 0.729, and the dependent variable is 0.879. A low R-square of at least 0.1 (or 10 percent) is acceptable on the condition that some or most of the predictors or explanatory variables are statistically significant [55], as all of the constructs are statistically significant so we can say that R square is acceptable in this case. Hence, we can say that our proposed model is highly significant and fulfills all the research instruments as it has been proven from the statistical tests, which endorse that the data is valid and accurate.

Hypothesis testing was performed to confirm the significance of the predicted hypothesis across each factor of the study as shown in Table 4. The criteria used to evaluate each hypothesis is the t-value across each loading. Significant t-values for the path loadings signify support for the proposed path, mean std deviation and t-statistic hypothesis. The cut-off criteria used was a t-value greater or equal to 1.645 for an alpha level of 0.05 [31,56]. Hypothesis testing for this study is shown in Table 4. Twelve hypotheses have an impact on the evaluation of technology-enabled online learning. Out of these, eleven hypotheses are accepted, while H11 addressing Technological Anxiety is rejected.

Table 4. Hypothesis-based decisions.

Hypothesis	Relationship	Std-Beta	Std-Error	t-Value	Decision	*p* Values
H1	ATT -> E	0.07	0.03	2.44	Supported	0.02
H2	CE -> E	0.08	0.03	2.5	Supported	0.01
H3	FC -> E	0.11	0.03	3.6	Supported	0
H4	IQ -> IU	0.17	0.05	3.26	Supported	0
H5	IQ -> US	0.21	0.03	6.07	Supported	0
H6	IU -> E	0.05	0.03	2.03	Supported	0.04
H7	SQ -> IU	0.2	0.06	3.52	Supported	0
H8	SQ -> US	0.29	0.04	7.25	Supported	0
H9	SYQ -> IU	0.22	0.05	4.32	Supported	0
H10	SYQ -> US	0.45	0.03	13.25	Supported	0
H11	TA -> E	0.02	0.02	1.13	Not Supported	0.26
H12	US -> E	0.65	0.03	20.4	Supported	0

The results of hypothesis testing indicate that eleven out of twelve hypotheses were accepted, whereas hypothesis H11 (Technological Anxiety having an impact on the evaluation of technology-enabled online learning) is rejected. For the 0.05 value of alpha, the t value greater than 1.645 indicates that the hypothesis is accepted. Hypothesis H1, for example, which states that Attitude has an impact on the evaluation of technology-enabled online learning, has a t-value of 2.44, which is greater than 1.645; hence, H1 can be accepted whereas Hypothesis H11 has a t-value of 1.13, which is less than 1.645; hence, H11 is rejected.

The results of this study indicate that all of the technology factors are important for the evaluation of technology-enabled online learning [3]. This means that the engineering students of developing countries, such as Pakistan, feel that the evaluation of technology-enabled online learning can be enhanced if modern technologies are effectively adopted. Moreover, it can be inferred from the results that students do not feel any 'Technological Anxiety' during technology-enabled online learning.

This means that the younger generation is quite familiar with technology, and they do not face any fear or anxiety while using technology for educational purposes. Overall, the results obtained from the students' responses indicate their satisfaction with online education in a pandemic-like situation.

3.2. Prioritization of Technology-Enabled Online Assessment Methodologies

This phase of the study intends to prioritize the assessment methods adopted in remote exams conducted during online education, considering the overall judgments of various stakeholders involved in the education system (faculty, students and policymakers from the ministry of education). Analytic Hierarchy Process (AHP)-based multi-actor multi-criteria analysis was deployed to rationally prioritize the screened alternatives and influencing factors.

As a standard first step of MCDM, it is required to prepare the list of assessment alternatives and the factors that affect their prioritized adoption. A large number of such factors were initially explored for the deliberations of education experts and selected students. A consensus was developed to include the six most crucial criteria for MAMCA-based evaluation, which are presented in Table 5 along with their inclusion rationale and literature evidence.

Table 5. Screened factors influencing the prioritization of the assessment methods.

Factors	Description	Rationale	Shreds of Evidence from Previous Studies on Education
Mental Health	Effect on the mental health of students and faculty during online assessments.	Since the students and faculty are not fine-tuned with the online assessments, it may seriously affect their mental health and performance.	[46,47,57–62]
Cost	It includes all types of costs associated with different modes of online exam conduct.	The system should be cost-effective to ensure its sustainability. Weaker financial circumstances make the 'Cost' factor more crucial in developing countries.	[12,16,17,58,63–66]
Convenience	The comfort level of students and faculty during online exam conduct.	Convenience always affects learning and assessment performance.	[67–71]
Integrity and Fairness	Maintaining the exam integrity and preventing unfair means.	It is always one of the crucial parameters for the conduct of any exam.	[32,33,72,73]
Accuracy	The adopted method must assess the student's learning accurately.	Accuracy is always one of the most important factors in the selection of any assessment method.	[66,74–80]
Availability of Infrastructure	Availability of facilities, such as internet connectivity, personal computers, proctoring system and other necessary gadgets.	Conduct of online exams is never possible without having sufficient technical infrastructure.	[2,12,16,56–58,81]

Four assessment alternatives had been short-listed by the experts concerning ground realities for online exam conduct in Pakistan. These include 'Project and Viva', 'Automated MCQs and Short Questions', 'E-Proctored Exams' and 'Open Book Written Exams'. All of these selected alternatives are for online assessment when the traditional paper-based exams with the physical on-campus presence of students and faculty are not possible. In the MCDM terminology, we use the term 'alternatives' for available options.

Since we are evaluating these options to facilitate policy makers in education sector, the term 'policy' is used for all these assessment methods. Six criteria are screened, which include fairness, accuracy, cost, conveniences, mental health and availability of infrastructure. The complete AHP hierarchy having shortlisted alternatives and criteria is shown in Figure 4. The arrowhead originated from each criterion and met with all the alternatives one by one are performing a multi-action decision-making analysis.

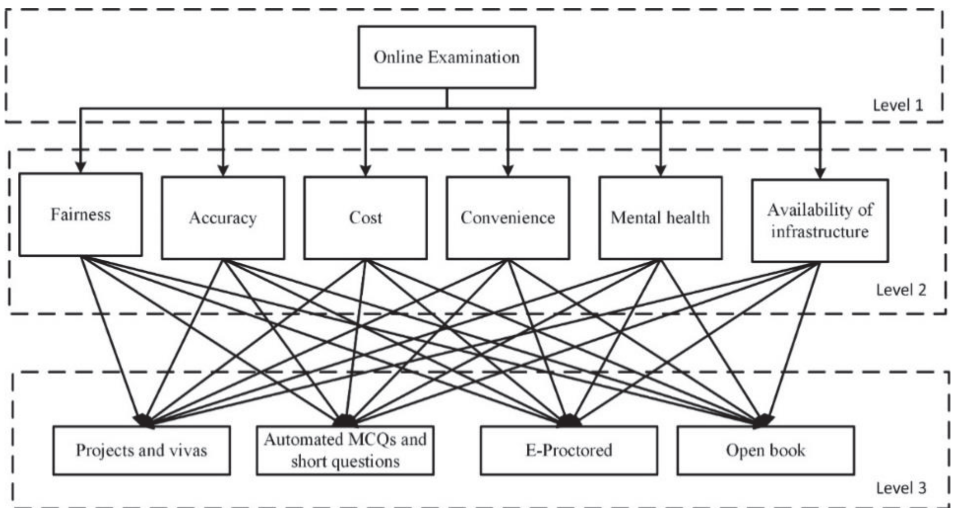


Figure 4. The AHP decision hierarchy with screened alternatives and criteria.

An AHP-based questionnaire consisting of a pair-wise comparison matrix of criteria and assessment alternatives using Saaty's 9-scale ratio was created and physically distributed to the faculty members and policymakers at their various locations and in individual encounters. Moreover, on-campus meetings were held with university students to gather their opinions on the prioritization of factors and alternatives using similar questionnaires. An AHP-based MAMCA was applied to the data obtained from all three stakeholders including students, faculty members from accredited universities and policymakers from the HEC [34]. For solutions to the created AHP models, commercially available software was used to reduce the computing effort. MAMCA results in the form of criteria weights and prioritized alternatives are shown in Figures 5 and 6.

Students and policymakers have given a top priority to mental wellbeing during online assessments. For faculty members, the availability of infrastructure is the most important factor, which is followed by Fairness and Mental Health. One of the interesting results obtained from the prioritization of criteria is that all three stakeholders have given the least importance to the Cost factor.

This means that there is a consensus among the stakeholders about sustainable investments in online education even if the incurred costs are high. Almost equal weightage is assigned to Fairness, which emerged as the second most important factor among all stakeholders. There seems a clear disagreement on the Availability of Infrastructure where the faculty members have assigned a priority that is much higher than those assigned by both the students and policymakers.

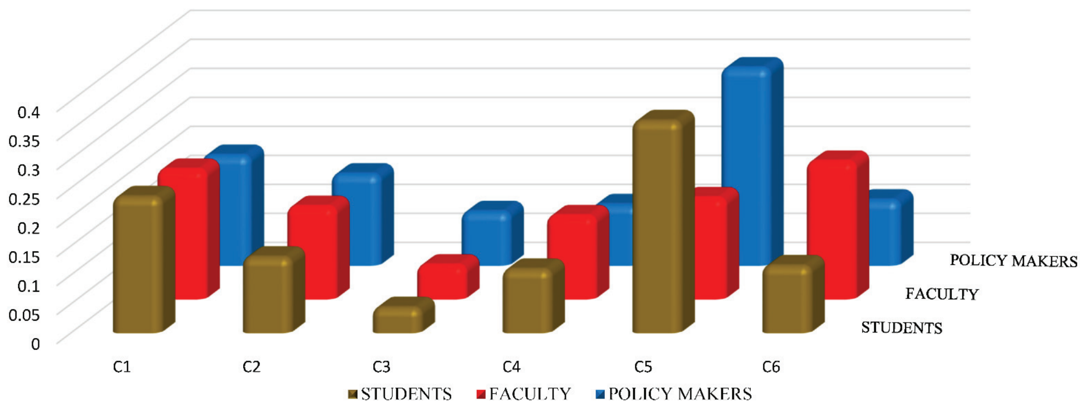


Figure 5. Stakeholder-wise Computed Weights for the Influencing Criteria. C1 = Fairness, C2 = Accuracy, C3 = Costs, C4 = Convenience, C5 = Mental Health, C6 = Infrastructure Availability.

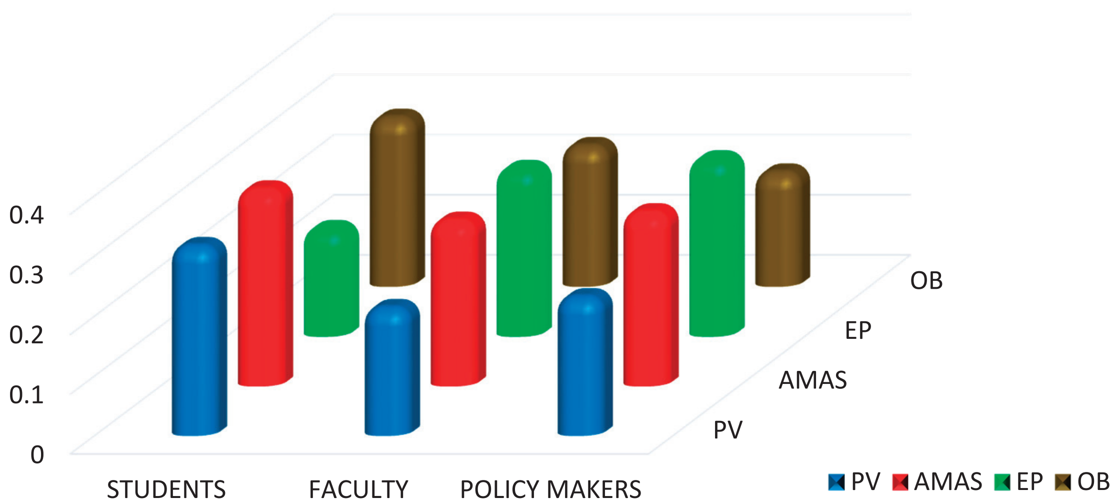


Figure 6. Computed weights of policy alternatives. PV = Projects and Viva's, AMAS = Automated MCQ's and Short Questions, EP = E-Proctored and OB = Open Book.

The results computed for the policy alternatives during the online assessment are compiled in Figure 6. Faculty has given a top priority to E-Proctored Exams and Automated MCQ's/Short Questions while giving a marginally lesser priority to the Open book exams. However, they have shown less interest in the conduct of viva and evaluating the assigned projects. This is likely due to the time and labor required to assess a large number of students orally using video calls. Contrary to faculty members and policymakers, the students gave the least importance to the E-proctored exam. Although Open Book exams seem a popular assessment method for students, they do not seem to be attractive to faculty and policymakers.

Overall results representing the perspectives of all stakeholders are summarized in Figure 7. Mental Health is the most important factor in the aggregate results followed by Fairness and Infrastructure Availability. Automated MCQs have secured a top ranking among the four online assessment policy alternatives, which is followed by the Open Book exams. There is only a marginal difference between E-Proctored Exams and Projects and Viva. Both of these alternatives seem less attractive when looking at results as a whole.

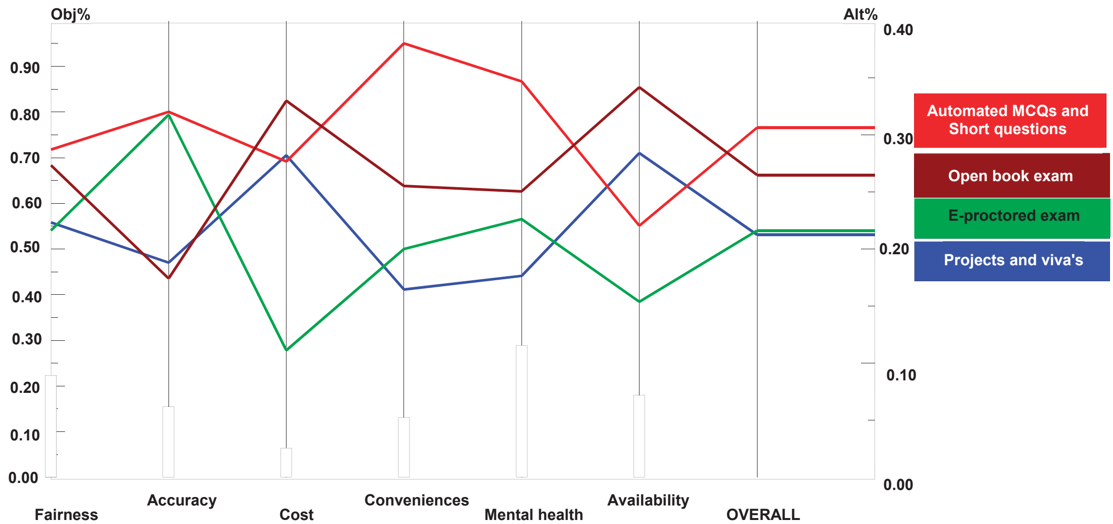
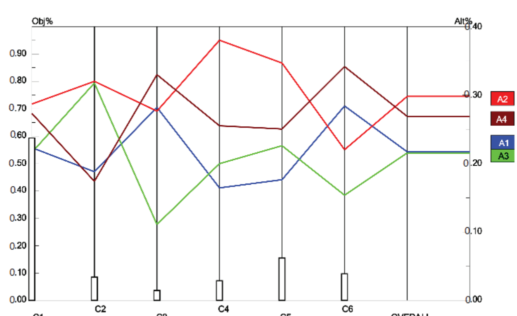


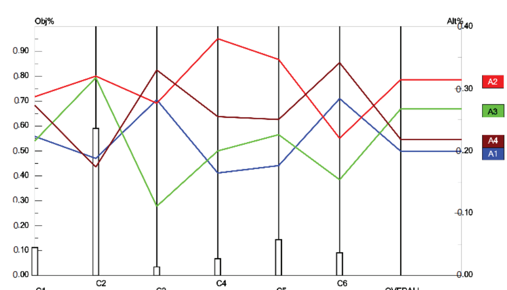
Figure 7. Original overall results (All stakeholders).

3.3. Analysing the Effect of Priority Variations

Sensitivity analysis is carried out by systematically altering inputs and observing their impact on the ranking list of assessment alternatives. Figure 8 shows six different scenarios where the priority weight input is changed for each criterion one by one. The names of influencing criteria are represented by horizontal lines, while their weights are scaled on the left vertical axis. Each alternative's performance is mapped to all the parameters and shown accordingly. On the right vertical axis, the overall scores earned by the options are highlighted. In each scenario, the weight of a single parameter is fixed at 60%, as recommended by [82]. Other parameters' strength varies in proportion to their original weights in a way that the sum of all the criteria weights stays equal to 100%. The outcome of the Sensitivity Analysis is summarized in Figure 8.

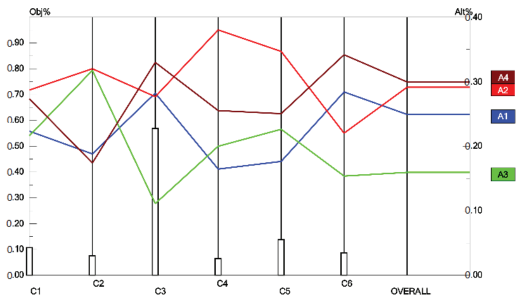


(**a**)

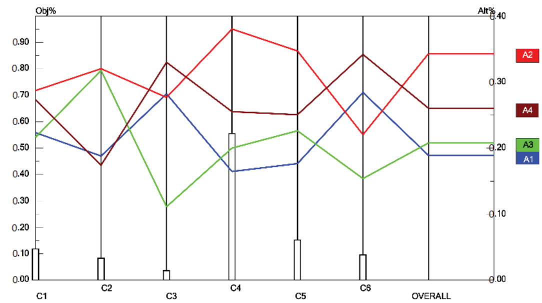


(**b**)

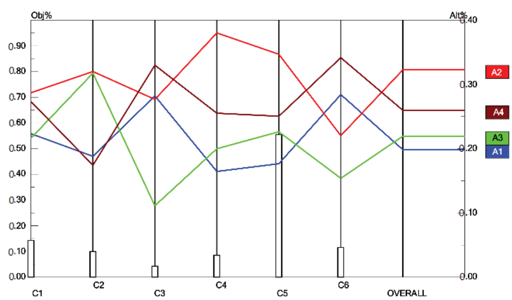
Figure 8. *Cont.*



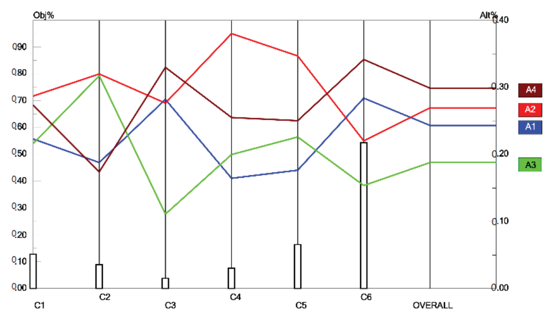
(c)



(d)



(e)



(f)

Criteria
C1 = Fairness
C2 = Accuracy
C3 = Cost
C4 = Convenience
C5 = Mental Health
C6 = Availability of infrastructure

Alternatives
A1 = Project and Viva
A2 = Automated MCQs and Short questions
A3 = E-Proctored exam
A4 = Open book exam

Figure 8. Performance Sensitivity Analysis of Alternatives. (**a**) With adjusted weight of Fairness (C1) equal to 60%. (**b**) With adjusted weight of Accuracy (C2) equal to 60%. (**c**) With adjusted weight of Cost (C3) equal to 60%. (**d**) With adjusted weight of Convenience (C4) equal to 60%. (**e**) With adjusted weight of Mental Health (C5) equal to 60%. (**f**) With adjusted weight of Availability of Infrastructure (C6) equal to 60%.

The rankings of the top-most Alternative (Automated MCQs and Short Questions) are preserved in four out of the six scenarios. The only two exceptions are the cases when Infrastructure Availability and Cost were given the top priorities. However, even in these extreme cases, it remained second only to the Open Book Exams. It can therefore be concluded that the top two alternatives are robust with respect to different scenarios. An almost similar pattern is observed for the two bottom-most alternatives. They preserve their bottom-most position in five scenarios.

Overall, it can be concluded that the top-two and bottom-two alternatives are mostly preserved in different perspectives, which means that 'Automated MCQs and Short Questions', and the "Open Book Exams" remain at the top while 'E-proctored' and 'Projects and Viva's' remain at the bottom. It can, therefore, be concluded that change in priority weights has not had a significant effect on the overall results.

4. Conclusions and Recommendations

Despite being one of the toughest challenges humanities has ever faced, the COVID-19 pandemic had an overall evolutionary effect on the education sector, especially in developing countries. This study shows that students of engineering institutions in Pakistan are ready to embrace the technology during online learning and assessment without affecting their academic productivity. In developing countries, such as Pakistan, it is not uncommon to face different unavoidable political, cultural and regional scenarios when the physical movement of students and educationist becomes bleak. This paper, therefore, opens a scientific horizon for policymakers to efficiently assess the students' learning using a technology-enabled online education system in the future.

While the first phase of this research, using hybrid methodologies, confirms the students' ability to efficiently handle the technology during online learning, the second phase rationally prioritizes factors and alternatives for online assessment. Overall, the mental health of students/teachers and the availability of infrastructure got the highest aggregate priority weights. There are only a couple of disagreements among the stakeholders on assigned factor weights. Students and policymakers have given the highest priority to 'mental health' whereas faculty members feel that infrastructure availability and fairness in online assessments are the most crucial factors. This is probably because of the reason that faculty members may feel that mental health is a function of system integrity and infrastructure availability.

The results reveal that there is a consensus among the stakeholders in assigning the highest priority to Automated MCQs/Short Questions via an efficiently designed online infrastructure for the conduct and management of online exams. Open Book exams emerged as the second most important alternative followed by the E-Proctored exams and Project/Viva-based exams. One significant difference of opinion observed in alternative ranking is that students seem less comfortable with E-proctored exams, which is given a higher priority by faculty and policymakers. Sensitivity analysis confirms the overall model robustness, although there are a few interesting exceptions when Infrastructure Availability and Cost are artificially assigned the highest weights.

The major contribution of this research is to rank and recommend the evaluation methodologies during distance education and online learning in Pakistan and other developing countries having similar socio-political and technological backgrounds.

4.1. Policy Implication

- This research provides a multidimensional set of results as flexible policy guidance for local as well as international education policymakers in setting the stakeholder priorities for the commencement of online education in developing countries.
- Whenever online education becomes the only option left to continue the education process worldwide, it requires an efficient system that considers all the factors and fulfills the needs of all stakeholders. This study can play a role in the development of an effective recommendation system for improved online education and exam conduct.
- The top two modes of examination suggested by stakeholders, after keeping in mind various factors, are the Automated MCQS/Short Questions and the Open Book exams.

4.2. Limitations and Recommendations

- It is worth noting that the results were achieved by solving the established models with specific data in relation to the current scenario. Political instability and financial uncertainty will have an impact on model inputs and outcomes. While the second phase takes all three stakeholders on board, the first phase is limited to students only. Another limitation of the study is that an equal weightage was given to the opinion of three stakeholders in the aggregate results. However, the differences in their assigned priorities are clearly highlighted and discussed.

This research can be expanded in the future by examining additional demographics, such as elementary and intermediate level students. Furthermore, the factors influencing different catastrophe situations would change, allowing those circumstances to be investigated using new elements. The study's findings can be extended to other developing countries with modest changes.

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education sciences

Article

An Investigation of Learning Needs in the Mining Industry

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Abstract: Mining operations are risky and often dangerous, with a high potential for accidents. Many of these accidents can be prevented by implementing safety measures. It is essential that mining companies take these measures seriously to protect the safety and wellbeing of their workers and ensure the sustainability of the industry. Among these measures, those related to training are addressed in this paper in relation to the ERASMUS+ project entitled DigiRescueMe, which aims at developing courses to increase the knowledge and level of awareness of miners, rescue members, and mining engineers and, consequently, reduce the death rate in mine accidents. For this goal, semi-structured interviews and surveys were implemented, and the collected data were analyzed. The mining industry is a wide domain connected to other sectors like universities, vocational schools, rescue centers, and agencies. For this reason, the investigations carried out herein engaged people from all these sectors to identify firstly the themes, secondly, the topics, and finally the knowledge levels corresponding to those themes and topics in order to determine the learning needs and translate them into requirements for the courses that will be developed during the project activities.

Keywords: learning needs; learning needs analysis; mining industry; learning; training

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1. Introduction

Mining is a critical industry that supplies essential resources for society, including coal, metals, and minerals. Mining operations are inherently risky and often dangerous, with a high potential for accidents. These accidents can lead to serious injuries, fatalities, and economic losses. There are many distinct types of accidents that can occur in mining, but some of the most common ones include cave-ins, explosions, fires, haulage accidents, and falls.

Cave-in accidents are caused by the collapse of underground mines, which can result from weak rock strata, over-extraction, or natural disasters like earthquakes. Explosions can occur due to the build-up of gases like methane or coal dust, which can ignite. Fires can be caused by faulty electrical equipment, friction, or the spontaneous combustion of coal. Haulage accidents occur when vehicles and equipment used in mining collide with each other, roll over, or overturn. Falls occur when miners fall from heights or when materials or equipment fall on them.

Mining accidents can be caused by several factors. The first is poor safety management, which means a lack of safety training for workers. Poorly maintained equipment or the use of faulty equipment can result in accidents. Human error can occur when workers are fatigued, inexperienced, or do not follow safety protocols. Also, natural disasters like earthquakes, floods, and landslides can cause mining accidents. Finally, ignoring safety regulations and guidelines can result in accidents. Several measures can be taken to prevent accidents in mining. Some of these measures are related to engineering, maintenance, equipment, and systems. Mining accidents can have profound consequences, including the loss of life, injuries, and economic losses. Many of these accidents can be prevented by implementing safety measures such as safety training, equipment maintenance, adherence to safety regulations, and improved ventilation. It is essential that mining companies take these measures seriously to protect the safety and wellbeing of their workers and to ensure the sustainability of the industry. Among these measures, those related to training were addressed in this study, and an initial analysis was conducted to find the real learning needs.

A review of fatal incidents in the Western Australian mining industry from 2000 to 2012 [1] analyzed data from the Western Australian Department of Mines and Petroleum and found that there were 52 fatal incidents during that time period. The incidents were categorized into six diverse types: vehicle-related, fall of ground, machinery-related, drowning, explosives-related, and other. The authors also found that most of the incidents occurred in the gold mining sector, and that the most common contributing factors were human error, inadequate training, and inadequate supervision.

In an analysis of fatalities and injuries that occurred in the United States mining industry between 2003 and 2014, with a focus on incidents involving mining equipment [2], the causes and contributing factors of these incidents were identified. The authors found that incidents involving mining equipment were the second most common cause of fatalities in the mining industry, accounting for 26% of all fatalities. They also found that the most common types of equipment involved in fatal incidents were haul trucks, followed by loaders and bulldozers. The authors identified several key factors that contributed to incidents involving mining equipment, including inadequate maintenance and inspection, operator error, and design and engineering deficiencies. They also named several strategies for improving safety in the mining industry, including the use of advanced technologies, improved training and education for equipment operators, and the development of more robust safety regulations and guidelines.

In a review of accident analysis and safety improvements in underground coal mines in China [3], the authors examined data on coal mine accidents and safety measures from various sources, including government reports, academic articles, and industry publications. They found that, despite considerable progress in reducing coal mine accidents in China, underground coal mining remains a hazardous activity, with a high number of fatalities and injuries. This paper discussed the main causes of coal mine accidents in China, which included inadequate safety management systems, a lack of training, and the inadequate maintenance of equipment. The authors also identified some key safety improvement measures, such as the use of modern mining technologies, enhanced safety regulations, the establishment of safety management systems, and better safety training for workers to promote a safety culture in the mining industry.

The learning needs for safety competence in the mining industry were explored in Ding, Yuan and Liu [4], and a framework for identifying and addressing these needs was proposed.

The learning and development needs of future mining workforces in light of technological advancements in the industry were examined in Williams and Huddlestone-Holmes [5], in order to argue that mining companies need to invest in upskilling their workers and fostering a culture of continuous learning to keep pace with technological change.

Moreover, a model for an industry-driven learning ecosystem in the mining industry that can support the upskilling of the workforce was proposed in Simms and Dixon [6] to help to address the skill gaps that currently exist in the industry and enable mining companies to adapt to changing technology and market conditions.

Attention has been paid to training and learning, but although many research activities have been conducted and several papers have been published in recent years on the topic of learning needs in the mining industry, there is still a lot of confusion as to both the methodological approaches to follow and the issues on which it is appropriate to intervene.

The focus of work pedagogy is promoting learning and development in the workplace by referring to the theories and assumptions related to knowledge and learning that underlie educational practices, shaping the ways in which workers engage in learning activities and acquire new knowledge and skills. One important dimension of the epistemological framework of work pedagogy is the practical–experiential dimension [7]. This dimension emphasizes the importance of direct learning experiences, where workers engage in activities that directly apply to their work tasks and responsibilities. This approach is grounded in the belief that learning is most effective when it is contextualized within a specific work environment and is closely aligned with the goals and needs of the organization [8]. Another important aspect is considering not only the technical skills and knowledge needed for work tasks, but also the social, emotional, and psychological dimensions of learning and development. The aim is to create a positive work environment that supports workers' wellbeing and promotes their engagement and motivation [9]. These principles are fundamental for the mining industry, where the conditions of work are hard and the wellbeing of workers is one of the goals of any initiative, especially if its aims are learning and training. These were the main reasons behind the learning needs assessment conducted in this research.

2. Learning Needs Analysis

Regardless of the learning objectives, which, according to their nature, can be based in the cognitive (mental), affective (attitude), and psychomotor (physical) domains [10], learning needs analysis is a domain in which scientists and pedagogists have conducted studies and research and published key ideas and perspectives. In the field of early childhood education, Maria Montessori is a pioneering figure who emphasized the importance of seeing and understanding the individual needs and interests of each child [11]. She believed that children have an innate desire to learn, and that the role of the educator is to create an environment that supports this natural curiosity. Montessori encouraged teachers to use observation and assessment tools to find each child's unique learning needs and to tailor their instruction accordingly. Many years later, Loris Malaguzzi, founder of the Reggio Emilia approach to early childhood education, emphasized the importance of collaboration and dialogue in learning needs analysis [12]. He believed that teachers should collaborate closely with parents, other educators, and the learners themselves to find their strengths, interests, and areas of challenge. Malaguzzi also emphasized the importance of creating a learning environment that is responsive to the social and cultural context of the learners and values creativity and exploration.

Contemporary Italian pedagogists, much like their predecessors, believe that learning needs analysis is still a critical aspect of effective education. They recognize that every learner has unique needs, interests, and abilities, and that a one-size-fits-all approach to teaching is not effective. Instead, they advocate for a personalized approach that considers each learner's individual circumstances.

The importance of a holistic approach to learning needs analysis has been emphasized [13]. Learners' needs are not limited to academic or cognitive aspects, but also include emotional, social, and spiritual dimensions. Educators should be encouraged to create a safe and supportive learning environment that addresses all these dimensions and promotes the development of the whole person. In addition to a focus on the whole person, contemporary pedagogy also emphasizes the importance of collaboration in the learning needs analysis process [14]. It recognizes that learners are not isolated individuals, but rather members of a larger community, and that the educational process should reflect this. Teachers should collaborate closely with parents, other educators, and community members to identify the needs of learners and create a learning environment that is responsive to their unique circumstances. Overall, learning needs analysis is a critical aspect of effective education, since every learner is unique, and a personalized approach that takes into account the whole person is essential: a learner-centered approach that values collaboration, creativity, and play and creates a safe and supportive learning environment for all learners. Overall, educators from all over the world have emphasized the importance of a learner-centered, holistic, and collaborative approach to learning needs analysis in higher education, industries, and professional training [15–18]. They have recognized the importance of tailoring training and education to the specific needs and goals of individual learners, and of considering the broader social, cultural, and ethical dimensions of learning.

They have also emphasized the importance of promoting critical thinking, creativity, and social responsibility, in addition to technical skills. Finally, they have emphasized the importance of collaboration between employers, educators, and learners in the learning needs analysis process in order to develop training programs that are relevant, practical, and adaptable to the changing needs of industries.

Needs analysis is a critical first step in designing an effective training intervention plan. Conducting a thorough needs analysis helps trainers to identify the specific knowledge, skills, and abilities that learners need to acquire to improve their job performance. By taking a systematic and data-driven approach to needs analysis, trainers can ensure that the training program is tailored to meet the needs of the target audience and is aligned with the goals of the organization.

The ADDIE model is a widely used instructional design framework that can be used to guide the needs analysis process [19]. The ADDIE model stands for Analysis, Design, Development, Implementation, and Evaluation. The Analysis phase of the ADDIE model is when needs analysis takes place. During this phase, trainers gather data about the current job performance of the target audience, the specific tasks and responsibilities that the training will address, and the organizational goals that the training program is intended to support.

The importance of conducting a needs analysis as part of the Analysis phase of the ADDIE model cannot be overstated. Needs analysis helps trainers to identify the specific knowledge, skills, and abilities that learners need to obtain to improve their job performance [20]. It also helps trainers to determine the right instructional methods, materials, and delivery methods that will best meet the needs of the target audience. Without a thorough needs analysis, trainers may create a training program that is not effective in addressing the specific needs of the target audience or that does not align with the goals of the organization.

3. The Investigation Activities

3.1. The Project and Themes

The activities described in this paper are related to the ERASMUS+ project entitled "Standardization and Digitalization of Rescue Education in Mining" (project acronym: DigiRescueMe). The project partners are from Turkey, Poland, Portugal, and Italy. DigiRescueMe will develop several innovative products to increase the knowledge and level of awareness of miners, rescue team members, and mining engineers and, consequently, decrease the death rate in mine accidents caused by unsafe or slow rescue processes.

In this project, semi-structured interviews and surveys were implemented, and the collected data were analyzed to identify the needs and translate them into learning requirements in terms of specific topics to address and approaches and methodologies to adopt.

Among the goals of the project was planning a curriculum, including the aims, content, processes, and scenarios, which were all identified by an initial exploratory investigation. In fact, courses will be designed to supply an answer to the learning needs identified herein.

The mining industry is a wider domain than most imagine. This sector may be linked, directly or indirectly over longer periods, to other sectors like universities, vocational schools, rescue centers, and agencies, to mention just the most probable.

For this reason, the investigations carried out herein engaged people from all these sectors to identify firstly the themes, secondly the topics, and finally the knowledge levels corresponding to those themes and topics.

In order to confirm what is written in the referenced literature, interviews were conducted during the writing of the project proposal, and focus groups were formed when the project started by engaging experts from mining companies (in Turkey and Poland); universities (in Turkey, Poland, Portugal, and Italy); and schools (in Turkey). In particular, the main findings were related to: the importance of risk management in the mining industry and methodologies and tools for identifying, assessing, and managing risks [21,22];

the critical role of mine rescue teams in responding to emergencies in the mining industry and the challenges and best practices associated with mine rescue operations [23]; and the challenges faced by workers in the mining industry and the impact of these challenges on mental health and wellbeing [24,25].

Thus, based on these studies, three themes were considered:

- Risk assessment;
- Mine rescue;
- Mental wellbeing.

Afterwards, experts identified aspects, concepts, and procedures related to these themes. Using this information, the items identified within the three topics were shared by the team of experts and, through online meetings and email exchanges, they were reviewed, cleaned up in order to avoid typos or duplications, and organized in a presentable form to facilitate investigations including surveys and the analysis of people's real needs.

Three questionnaires were prepared and delivered by COFACTOR, a Google-based system (Google Forms and Sheets) able to administer questionnaires and automatically collect and analyze data that was specifically conceived for learning needs analysis [26].

The first section of the questionnaires aimed at collecting general information on participants in the survey including: email address, country, region/city, sex, education level, current school/university/enterprise, occupation, and length of service.

The second section of each questionnaire had specific items, for which the participants had to declare, on a five-level scale, their own confidence (i.e., how much they knew about that topic).

As shown in Table 1, the questionnaire on Risk assessment had 43 items classified into three categories.

Table 1. Categories and number of items for Risk assessment.

Category	Number of Items
Terminology and definitions	21
Risk management	11
Risk analyses and methods	11

As shown in Table 2, the questionnaire on Mine rescue had 73 items classified into ten categories.

Table 2. Categories and number of items for Mine rescue.

Category	Number of Items
Basic information	5
Formal law aspects of rescuing	2
Structure of rescue	8
Sorts and organization of rescue activities	4
Equipment used in rescue	6
Hazard classification	15
Natural hazards	18
Ergonomic, organizational, and human factor risks	4
Technical hazards	2
Methods of prevention	9

As shown in Table 3, the questionnaire on Mental wellbeing had 44 items classified into five categories.

Table 3. Categories and number of items for Mental wellbeing.

Category	Number of Items
Basic information	2
Risks for work-related stress	10
Stress reactions	6
Stress factors	16
Sentinel events	10

3.2. The Participants

These investigation activities engaged an overall number of 281 participants distributed among the three surveys, mainly from Turkey and Poland. For these surveys, there was no probabilistic sampling, but they engaged all the participants from the mine companies, universities, and schools who gave their consent to take part. Details regarding the participants are collected in Tables 4–6.

Table 4. Number and sex of participants.

Sex	Risk Assessment	Mine Rescue	Mental Wellbeing
Man	144	163	116
Woman	28	58	66
Not declared	4	3	3
TOTAL	**176**	**248**	**185**

Table 5. Country of participants.

Country	Risk Assessment	Mine Rescue	Mental Wellbeing
Poland	35	44	48
Turkey	135	194	132
Other country	2	7	2
Not declared	4	3	3
TOTAL	**176**	**248**	**185**

Table 6. Declared education level of participants.

Education Level	Risk Assessment	Mine Rescue	Mental Wellbeing
PhD	2	2	1
Master’s degree	46	61	47
Bachelor’s degree	6	4	31
High school	86	118	64
Junior high school	18	37	18
Primary school	3	8	9
Not declared	15	18	15
TOTAL	**176**	**248**	**185**

Regarding the participants, to relate their identified learning needs to their declared educational level, institution, country, and role, different clusters were defined, as shown in Tables 7 and 8.

Table 7. Clusters of participants based on institution and country.

	Risk Assessment			Mine Rescue			Mental Wellbeing		
	Poland	**Turkey**	**TOT**	**Poland**	**Turkey**	**TOT**	**Poland**	**Turkey**	**TOT**
University	9	36	45	7	53	60	8	33	41
Enterprise	18	64	82	21	94	115	18	62	80
School	8	28	36	14	43	57	19	24	43
Other	0	1	1	1	2	3	2	7	9
EMPTY		12	12	1	12	13	1	11	12
TOT	**35**	**141**	**176**	**44**	**204**	**248**	**48**	**137**	**185**

Table 8. Clusters of participants based on role.

	Risk Assessment			Mine Rescue			Mental Wellbeing		
	Poland	**Turkey**	**TOT**	**Poland**	**Turkey**	**TOT**	**Poland**	**Turkey**	**TOT**
Technical worker	16	65	81	16	90	106	10	60	70
Rescue member	0	5	5	2	8	10	9	5	14
Supervisor	5	0	5	6	0	6	4	0	4
Engineer	3	7	10	6	9	15	4	5	9
Student	7	30	37	11	38	49	16	27	43
University student	4	22	26	3	41	44	4	24	28
Other	0	2	2	0	2	2	0	4	4
EMPTY	0	10	10	0	16	16	1	12	13
TOT	**35**	**141**	**176**	**44**	**204**	**248**	**48**	**137**	**185**

3.3. The Collected Data

For each topic in the questionnaires, there was an item with answers in the range of 1 to 5. A value of 1 means no knowledge about that topic (0%), and a value of 5 means full knowledge about that topic (100%). The three questionnaires are presented in the Appendices A–C.

For the 43 items on Risk assessment, the Cronbach's alpha was calculated. Its value, 0.98, meant that this questionnaire had internal consistency. Figure 1 shows the average knowledge declared on Risk assessment by the participants regarding the three identified categories of the addressed topics. Figure 2 shows the average knowledge declared by the participants on each item of Risk assessment.

For the 73 items on Mine rescue, the Cronbach's alpha was calculated. Its value, 0.99, meant that this questionnaire had internal consistency. The diagram in the Figure 3 shows the average knowledge declared regarding Mine rescue by the participants in terms of the 10 identified categories of the addressed topics. Figure 4 shows the average knowledge declared by the participants regarding each item of Mine rescue.

For the 44 items on Mental wellbeing, the Cronbach's alpha was calculated. Its value, 0.97, meant that this questionnaire had internal consistency. The diagram in the Figure 5 shows the average knowledge declared on Mental wellbeing by the participants in terms of the five identified dimension categories of the addressed topics. Figure 6 shows the average knowledge declared by the participants on each item of Mental wellbeing.

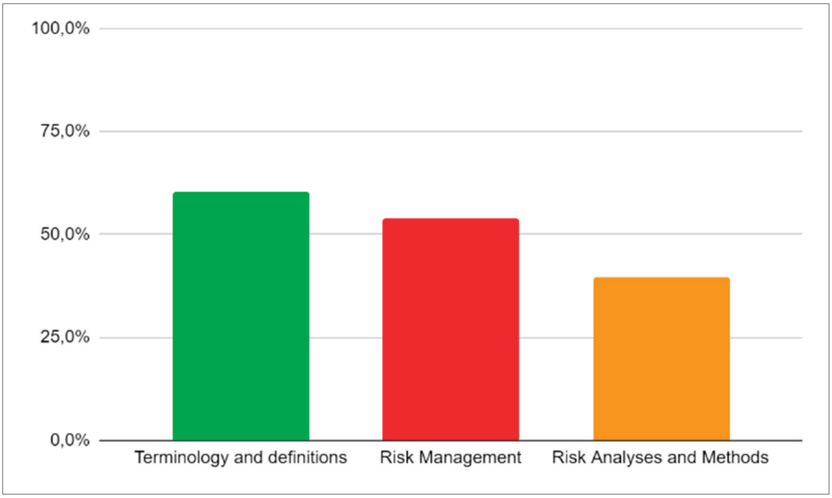

Figure 1. Knowledge level of participants regarding the categories of Risk assessment.

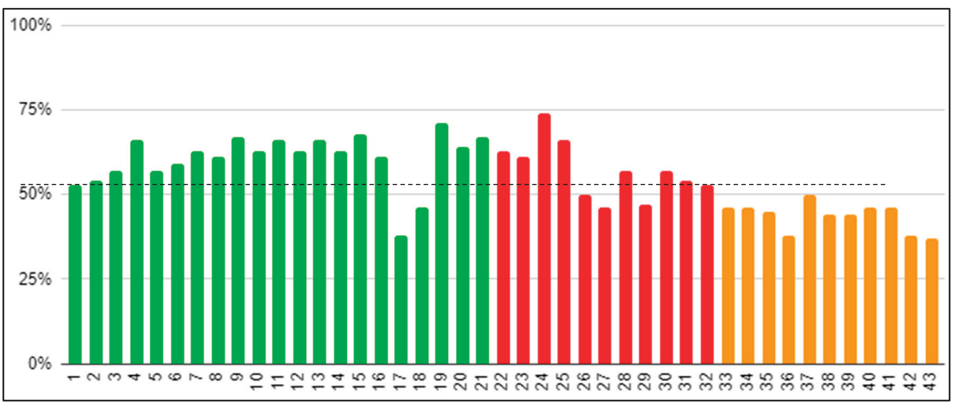

Figure 2. Knowledge level of participants regarding the items of Risk assessment.

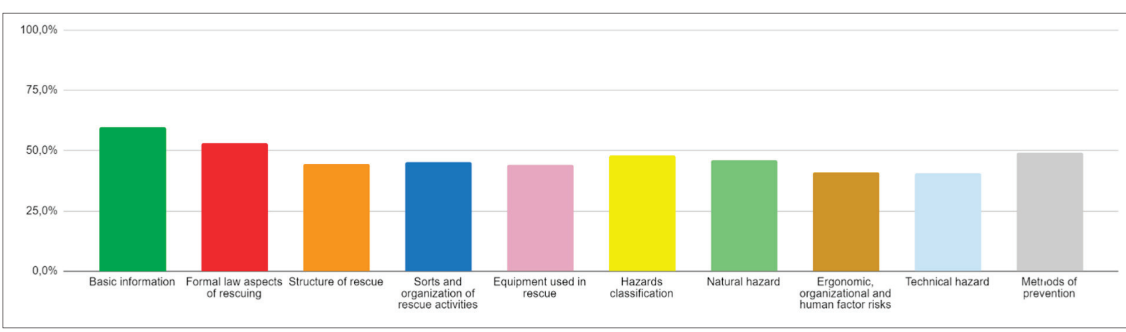

Figure 3. Knowledge level of participants regarding the categories of Mine rescue.

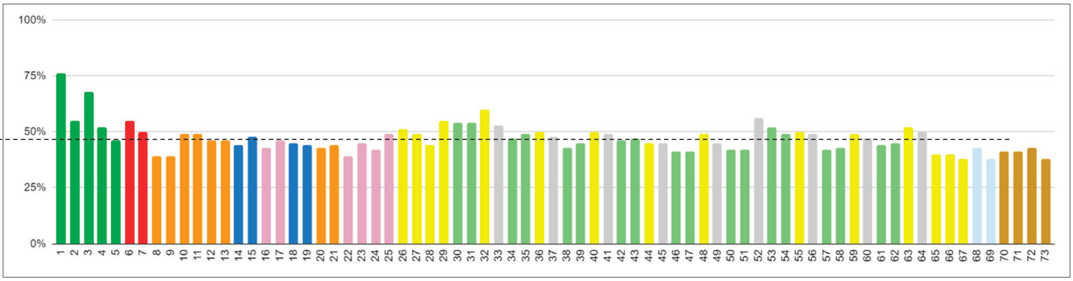

Figure 4. Knowledge level of participants regarding the items of Mine rescue.

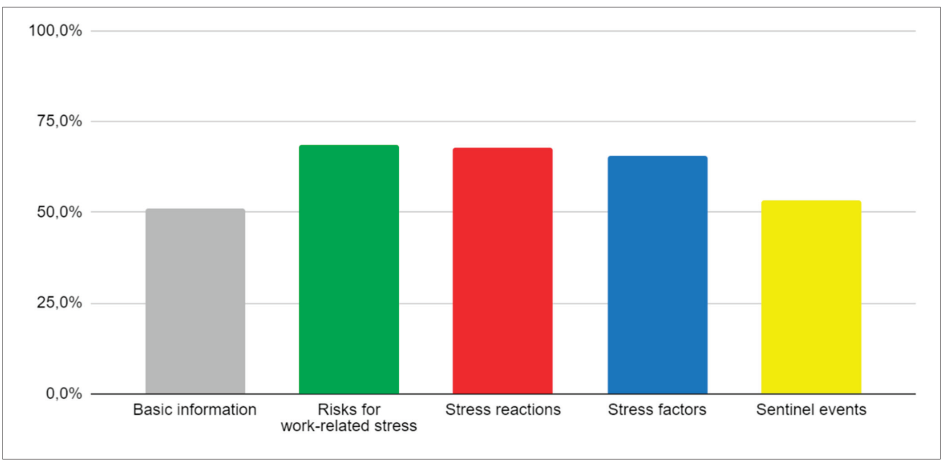

Figure 5. Knowledge level of participants regarding the categories of Mental wellbeing.

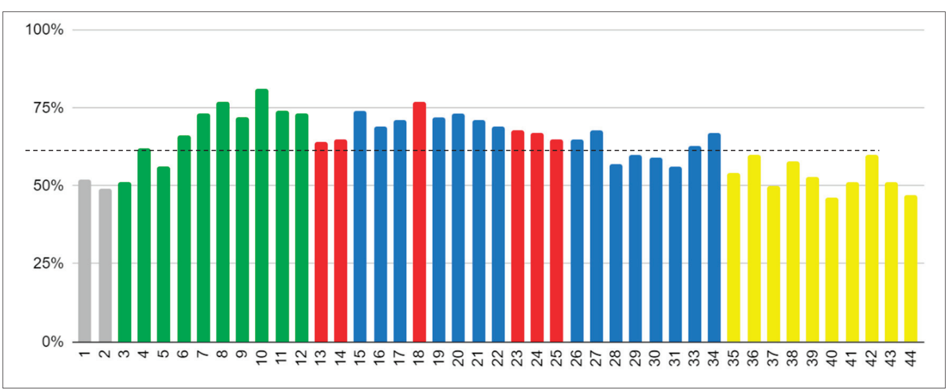

Figure 6. Knowledge level of participants regarding the items of Mental wellbeing.

4. Data analysis and Discussion

4.1. Data Analysis of Categories

The data collected on the categories were aggregated by considering all details declared by the participants. In this way, it was possible to distinguish them based on their country, sex, education level, institution, and role. These data are shown for each theme. Table 9 shows the data related to Risk assessment, Table 10 shows the data related to Mine rescue, and Table 11 shows the data related to Mental wellbeing.

Table 9. Knowledge declared by participants on categories of Risk assessment aggregated by country, sex, education level, institution, and role according to a 5-level scale (from 1 (low level of knowledge) to 5 (high level of knowledge)).

Risk Assessment	Terminology and Definitions	Risk Management	Risk Analyses and Methods
All (176 participants)	3.9	3.7	3.1
Country			
Poland	3.9	3.5	2.8
Turkey	3.9	3.8	3.2
Sex			
Men	3.9	3.6	3.0
Women	4.1	4.0	3.5
Education level			
PhD	4.5	4.2	3.9
Master's degree	4.0	3.7	3.0
Bachelor's degree	4.1	3.7	3.1
High school	3.9	3.7	3.1
Junior high school	3.5	3.4	2.8
Primary school	4.5	4.2	3.2
Institution			
University	4.1	3.9	3.3
Enterprise	3.9	3.6	2.8
School	3.7	3.6	3.3
Role			
Technical worker	3.9	3.6	2.8
Rescue member	4.4	4.5	4.1
Supervisor	3.9	3.4	2.8
Engineer	4.4	4.2	3.8
School student	3.5	3.4	3.1
University student	4.0	3.8	3.3

Regarding the data in Table 9, it is possible to note that in the "terminology and definitions" category, there were no differences between the two countries and minor differences based on sex (0.2). Wider differences could be found based on educational level (0.6), institution (0.4), and role (0.9), which could lead to different learning needs. In both the "risk management" and "risk analyses and methods" categories, there were differences between the two countries, sexes, educational levels, institutions, and roles. This meant that based on these aspects, the effective learning needs may be different and may depend on these learner's features.

Regarding the data in Table 10, it is possible to note that there were some features of the participants that may have influenced their learning needs, and others that seemed to have no effect on them. In fact, based on the country of the participants, there were no differences or slight differences (max 0.1) in the "formal law aspects of rescuing"; "ergonomic, organizational, and human factor risks"; and "technical hazards" categories. However, this feature seemed to significantly affect the other categories. Based on the sex of the participants, there were no differences or minor differences (max 0.2) in the "basic information", "structure of rescue", "sorts and organization of rescue activities", "hazard classification", "natural hazards", and "methods of prevention" categories. However, this feature of the participants affected both the "ergonomic, organizational, and human factor risks" and "technical hazards" categories.

Table 10. Knowledge declared by participants on categories of Mine rescue aggregated by country, sex, education level, institution, and role according to a 5-level scale (from 1 (low level of knowledge) to 5 (high level of knowledge)).

Mine Rescue	Basic Information	Formal Law Aspects of Rescuing	Structure of Rescue	Sorts and Organization of Rescue Activities	Equipment Used in Rescue	Hazard Classification	Natural Hazards	Ergonomic, Organizational, and Human Factor Risks	Technical Hazards	Methods of Prevention
All (248 participants)	3.8	3.6	3.3	3.3	3.3	3.4	3.3	3.2	3.2	3.5
Country										
Poland	4.4	3.6	3.8	3.7	3.5	3.7	4.1	3.2	3.2	3.9
Turkey	3.2	3.6	3.1	3.1	3.2	3.3	3.1	3.1	3.1	3.3
Sex										
Men	3.8	3.6	3.2	3.3	3.2	3.4	3.3	3.1	3.1	3.4
Women	3.8	3.7	3.3	3.2	3.2	3.5	3.4	3.4	3.5	3.5
Education level										
PhD	4.3	4.5	4.1	4.0	3.7	3.9	4.6	3.8	4.0	4.5
Master's degree	4.1	3.8	3.6	3.6	3.6	3.7	3.7	3.3	3.3	3.8
Bachelor's degree	4.2	4.3	3.5	4.0	3.6	3.7	3.6	3.5	3.6	3.6
High school	3.7	3.6	3.1	3.2	3.1	3.3	3.1	3.1	3.2	3.3
Junior high school	3.5	3.2	3.0	2.9	2.9	3.0	3.1	2.9	2.8	3.1
Primary school	4.1	3.6	3.7	3.7	3.5	4.0	3.8	3.5	3.9	3.8
Institution										
University	3.9	3.9	3.3	3.3	3.3	3.5	3.4	3.2	3.2	3.6
Enterprise	3.8	3.4	3.2	3.2	3.2	3.4	3.2	3.1	3.0	3.3
School	3.8	3.6	3.3	3.3	3.3	3.3	3.4	3.2	3.2	3.4
Role										
Technical worker	3.7	3.3	3.1	3.2	3.1	3.3	3.1	3.0	3.0	3.2
Rescue member	4.2	4.0	3.9	4.0	3.8	3.9	3.8	3.6	3.5	4.0
Supervisor	4.3	3.4	3.5	3.5	3.1	3.6	4.2	3.7	3.0	3.7
Engineer	4.5	4.5	4.3	4.4	4.2	4.3	4.4	4.3	4.2	4.4
School student	3.7	3.7	3.2	3.1	3.1	3.3	3.3	3.0	3.0	3.3
University student	3.8	3.9	2.9	3.1	3.1	3.6	3.3	3.5	3.5	3.8

The institution of the participants seemed to affect only the "methods of prevention" category and had no effect on the other categories.

Finally, based on both the education level and role of the participants, there were differences in all identified categories, and thus it was possible to relate these features of the participants to different learning needs.

Finally, regarding the data in Table 11, it is possible to note that most of the features of the participants could influence their learning needs, except the country, based on which there were no differences or slight differences (max 0.2) in all categories.

Table 11. Knowledge declared by participants on categories of Mental wellbeing aggregated by country, sex, education level, institution, and role according to a 5-level scale (from 1 (low level of knowledge) to 5 (high level of knowledge)).

Mental Wellbeing	Basic Information	Risks for Work-Related Stress	Stress Reactions	Stress Factors	Sentinel Events
All (185 participants)	3.6	4.1	4.2	4.1	3.7
Country					
Poland	3.6	4.0	4.1	4.1	3.6
Turkey	3.6	4.2	4.2	4.1	3.7
Sex					
Men	3.5	4.0	4.1	4.0	3.6
Women	4.2	4.4	4.4	4.3	3.8
Education level					
PhD	4.0	4.1	4.3	4.4	3.5
Master's degree	3.7	4.2	4.2	4.1	3.7
Bachelor's degree	3.6	4.3	4.4	4.4	3.8
High school	3.5	4.0	4.1	3.9	3.5
Junior high school	3.5	4.0	3.8	3.8	3.3
Primary school	4.0	4.4	4.5	4.5	4.3
Institution					
University	3.5	4.3	4.3	4.3	3.9
Enterprise	3.6	4.1	4.2	4.1	3.4
School	3.6	4.0	4.0	4.0	3.8
Role					
Technical worker	3.5	4.1	4.2	4.0	3.3
Rescue member	4.1	4.4	4.3	4.4	4.0
Supervisor	3.5	4.0	4.4	4.1	3.6
Engineer	4.0	4.5	4.6	4.4	4.0
School student	3.6	3.8	3.8	3.8	3.6
University student	3.5	4.3	4.4	4.4	4.0

Other features like sex, education level, institution, and role had an effect on all the categories, and thus they influenced the identified learning needs.

4.2. Data Analysis of Items

For all the data collected on the items, a presentation like that for the categories was chosen by considering all the details declared by the participants. For each theme, only a few items were chosen. These were the items for which the declared knowledge was less than the average value, and thus they could be seen as critical items. Moreover, statistical indexes were calculated to measure the central tendency and dispersion for each questionnaire. For the items of risk assessment, the value of the mean was 3.67, the value of the median was 3.74, the value of the mode was 4.19, and the value of the standard deviation was 1.21. For the items of mine rescue, the value of the mean was 3.40, the value of the median was 3.48, the value of the mode was 4.38, and the value of the standard deviation was 1.37. For the items of mental wellbeing, the value of the mean was 3.99, the value of the median was 4.39, the value of the mode was 4.84, and the value of the standard deviation was 1.12.

The referenced average values for the items are represented in Figures 2, 4 and 6 by dotted lines. Table 12 shows these data for risk assessment, Table 13 shows these data for mine rescue, and Table 14 shows these data for mental wellbeing.

Table 12. Knowledge declared by participants on the most critical items of Risk assessment aggregated by country, sex, education level, institution, and role according to a 5-level scale (from 1 (low level of knowledge) to 5 (high level of knowledge)).

Category	Risk Analyses and Methods					
Item n.	**33**	**34**	**35**	**36**	**42**	**43**
All (176 participants)	3.2	3.2	3.2	3.0	2.5	2.5
Country						
Poland	3.1	3.2	3.1	3.2	1.8	2.0
Turkey	3.2	3.2	3.2	3.0	2.7	2.6
Sex						
Men	3.1	3.1	3.1	3.0	2.4	2.4
Women	3.6	3.4	3.6	3.3	3.1	3.1
Education level						
PhD	4.0	4.0	4.0	4.0	3.5	3.5
Master's degree	3.0	3.1	3.3	3.1	2.4	2.2
Bachelor's degree	3.5	3.3	3.2	3.3	1.8	2.2
High school	3.2	3.2	3.2	3.1	2.6	2.6
Junior high school	3.1	2.9	2.7	2.4	2.4	2.6
Primary school	3.0	3.3	3.7	3.3	2.3	3.0
Institution						
University	3.2	3.3	3.4	3.4	2.9	2.8
Enterprise	3.1	2.9	3.0	2.7	2.1	2.1
School	3.3	3.5	3.3	3.2	2.8	2.9
Role						
Technical worker	3.0	2.9	3.0	2.7	2.0	2.0
Rescue member	3.6	4.2	4.4	3.8	4.0	3.8
Supervisor	3.0	3.2	3.0	3.6	1.4	1.4
Engineer	3.9	3.8	3.9	3.9	3.5	3.6
Student	3.1	3.2	3.0	3.0	2.8	2.9
University student	3.2	3.3	3.3	3.4	2.9	2.8

The most critical items of Risk assessment in Table 12 were in the "risk analyses and methods" category. Moreover, it is possible to note that most of the features of the participants could influence their learning needs, except the country, based on which there were no differences or small differences (max 0.2) in item 33 (*I can classify the risk assessment methods*), item 34 (*I can make a comparison between qualitative and quantitative risk assessment methods), item 35 (*I can detect the right risk assessment method for my workplace*), and item 36 (*I know which members are included in a risk assessment team*). This meant that, for these items, the effective learning needs seemed to be independent of this feature of* the participant.

The most critical items of *mine rescue* in Table 13 were in the following categories: "structure of rescue"; "equipment used in rescue"; "hazard classification"; "technical hazards"; and "ergonomic, organizational, and human factor risks".

Table 13. Knowledge declared by participants on the most critical items of Mine rescue aggregated by country, sex, education level, institution, and role according to a 5-level scale (from 1 (low level of knowledge) to 5 (high level of knowledge)).

Category	Structure of Rescue	Equipment Used in Rescue	Hazard Classification	Technical Hazards	Ergonomic, Organizational, and Human Factor Risks
Item n.	**9**	**22**	**67**	**69**	**73**
All (248 participants)	3.0	3.0	3.1	3.1	3.1
Country					
Poland	3.9	3.2	2.8	2.9	3.1
Turkey	2.8	3.0	3.1	3.1	3.0
Sex					
Men	3.1	3.0	3.0	3.0	3.0
Women	3.0	3.1	3.3	3.4	3.3
Education level					
PhD	4.5	3.5	3.5	3.5	2.5
Master's degree	3.4	3.3	3.0	3.0	3.1
Bachelor's degree	3.0	3.2	3.7	3.5	3.2
High school	2.8	2.9	3.1	3.1	3.1
Junior high school	3.0	2.8	2.8	2.7	2.8
Primary school	3.5	3.3	3.7	3.8	3.8
Institution					
University	3.0	3.0	3.2	3.1	3.0
Enterprise	2.9	2.9	3.0	2.9	3.1
School	3.2	3.3	3.2	3.2	3.1
Role					
Technical worker	2.8	2.9	3.0	2.9	3.0
Rescue member	3.4	3.5	3.5	3.3	3.6
Supervisor	3.6	2.6	2.3	2.6	3.5
Engineer	4.4	4.0	4.1	4.0	4.4
Student	3.0	3.0	2.9	3.0	2.8
University student	2.5	2.5	3.5	3.4	3.6

Some features of the participants had no effect on some items. In particular, the country did not affect or had a small influence on item 22 (*I can identify the equipment used in mine rescue depending on the hazard that occurs in a particular rescue operation*), item 69 (*I can identify the most important technical hazards occurring in surface mining due to workstations*) and item 73 (*I can identify the most important organizational hazards that occur at mining workplaces*). Instead, it affected other items. The sex of the participant did not affect either item 9 (*I know who is responsible for the condition of mine rescue at a mining plant*) or item 22 (*I can identify the equipment used in mine rescue depending on the hazard that occurs in a particular rescue operation*). However, this feature had an influence on other identified items. The institution of the participant had no effect or a small influence on both item 67 (*I know the prevention of the most important hazards occurring in surface mining*) and item 73 (*I can identify the most important organizational hazards that occur at mining workplaces*). However, it affected other items. Finally, other features of the participants affected these items, and thus they had an influence on the detected learning needs.

Table 14. Knowledge declared by participants on the most critical items of Mental wellbeing aggregated by country, sex, education level, institution, and role according to a 5-level scale (from 1 (low level of knowledge) to 5 (high level of knowledge)).

Category	Risks for Work-Related Stress	Sentinel Events			
Item n.	**3**	**36**	**39**	**42**	**43**
All (185 participants)	3.5	3.5	3.4	3.5	3.4
Country					
Poland	3.3	3.0	3.3	3.6	3.5
Turkey	3.6	3.7	3.5	3.6	3.4
Sex					
Men	3.4	3.4	3.4	3.5	3.4
Women	4.0	3.7	3.7	3.8	3.4
Education level					
PhD	4.0	2.0	4.0	4.0	4.0
Master's degree	3.6	3.5	3.5	3.4	3.6
Bachelor's degree	3.6	3.8	3.6	3.6	3.8
High school	3.3	3.3	3.3	3.6	3.1
Junior high school	3.1	3.2	3.1	3.3	3.0
Primary school	3.8	4.2	3.8	4.4	4.3
Institution					
University	3.5	3.9	3.8	3.8	3.7
Enterprise	3.3	3.4	3.1	3.2	3.1
School	3.8	3.3	3.6	3.8	3.7
Role					
Technical worker	3.4	3.2	3.1	3.2	3.0
Rescue member	4.0	4.0	3.5	3.7	4.0
Supervisor	2.7	3.0	3.2	3.7	3.7
Engineer	4.3	3.7	4.1	4.0	4.1
Student	3.5	3.3	3.5	3.6	3.5
University student	3.3	4.0	4.1	3.8	3.8

The most critical items of Mental wellbeing in Table 14 were in two categories: "risks for work-related stress" and "sentinel events". Among these items, only item 43 (*The malaise of a worker results from his/her low job satisfaction*) showed no differences based on sex and slight differences based on country (0.1) and institution (0.1). For other items, there were differences based on the features of the participants, which meant that they were effectively related to their own learning needs.

5. Discussion

The world of the mining industry, however ancient, is still a context to which multiple production activities are anchored. For this reason, the set of professional figures and their cultural backgrounds and education levels are also very varied. There are mining companies that have needs and problems of many types, on which the specific training activities of schools and universities converge and for which the innovation and technology transfer activities of universities and research centers are fundamental.

However, this is a dangerous area, and therefore it is a fertile ground for initiatives that have the aim of improving the safety and health of those who work in the industry. For the same reason, training activities are also welcomed when they are related to hazards, risks, rescues, and the delicate objective of saving human lives. The recurring problem, however, is to make these activities more effective and efficient so as to reconcile them with everyday work and life and maximize results by minimizing their costs. It is known that the analysis of needs is the first fundamental step to achieving this goal. Unfortunately, for this very varied area, there are no specific studies that have been conducted to investigate and analyze the training needs.

The DigiRescueMe project was born precisely for this reason: to intervene on issues and problems pertinent to the mining industry by preparing targeted training courses.

In this investigation, a large amount of data was collected. Only a few of them were presented and analyzed herein with the aim of identifying learning gaps among the participants regarding mine rescue, risk assessment, and mental wellbeing. Figure 7 represents these gaps in order to clarify where the learning needs lie and lead the future development of customized and more effective learning courses for particular learner profiles [27].

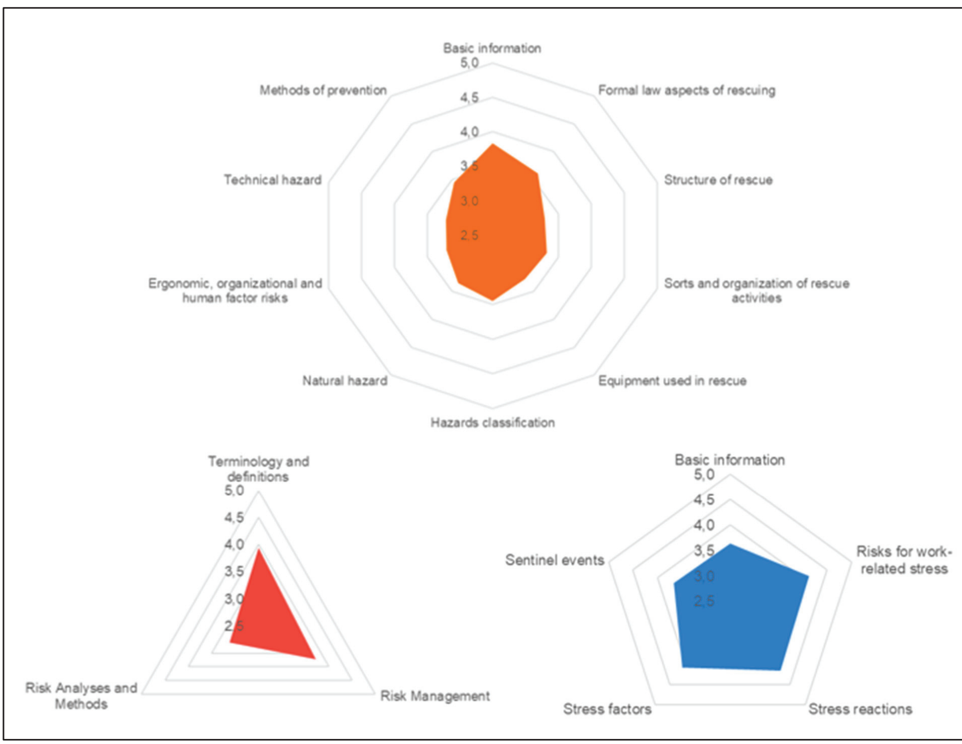

Figure 7. Learning gaps among participants regarding Mine rescue, Risk assessment, and Mental wellbeing according to a 5-level scale (from 1 (low level of knowledge) to 5 (high level of knowledge)).

6. Conclusions

Learning needs analysis is a process that helps identify the specific learning needs of adult learners. This process is crucial to create effective adult education courses, as it ensures that the content and approach are tailored to the learners' specific needs and goals.

Adult learners have different learning needs than children, as their motivations and goals for learning are often different. Adults are typically motivated by practical goals, such as advancing their careers or gaining new skills to enrich their personal lives. They also tend to have more life experience and knowledge than children, which can affect their learning styles and preferences [28]. To effectively meet the learning needs of adult learners, instructors must understand: learners' prior knowledge and experiences, their goals and motivations for learning, their preferred learning styles and approaches, their level of engagement and participation, and finally the challenges they face and obstacles to learning they must overcome. By understanding these factors, instructors can design courses that are relevant, engaging, and effective for adult learners [29].

Thus, this kind of analysis is a critical step in creating effective courses for adult learners. In fact, the activities described in this paper may lead to tailored content, improved learning outcomes, the increased engagement of participants, and reduced costs.

The learning needs analysis conducted in this project will help instructors to tailor course content to the specific needs of the adult learners in terms of the identified themes and topics related to Risk assessment, Mine rescue, and Mental wellbeing. By identifying the learners' goals, preferences, and prior knowledge, instructors can ensure that the content is relevant and engaging for all contexts (countries and institutions), all the abovementioned education levels, and all the roles the learners actually have or aim to have [30].

What emerged from the learning needs analysis was that the training interventions will be prepared in the three considered macro-areas with the aim of increasing knowledge, skills, and attitudes on not only a strictly cognitive and technical-scientific level, but, above all, a socio-psychological level. What has been stated translates into a plan for skills where strategies and techniques of a socio-constructivist nature will be adopted, paying particular attention to the active role of the learners in their learning processes. The teaching interventions will be planned by proposing real situations, enhancing the student's concrete experience in real or simulated contexts. For this reason, theoretical interventions will be followed by laboratory activities that will require, for example, the integration of content from different disciplines in the analysis and resolution of real cases through the adoption of methods to critically interpret the observed phenomena.

These preliminary studies ensure that both the course content and the approach that will be developed in the DigiRescueMe project will be aligned with the learners' goals and preferences, leading to improved learning outcomes. In this way, learners will feel that the course content is relevant to their needs and interests, so they will be more likely to be engaged and motivated to learn. This approach will surely increase engagement and participation. Learners will not feel that they are wasting time, and the involved institutions will be sure that they are investing resources and money in the right way by seeing that the courses are designed effectively and efficiently for the people working and or studying there.

In conclusion, learning needs analysis is a critical process for creating effective courses for adult learners. By understanding the learners' goals, preferences, and prior knowledge, instructors can design courses that are relevant, engaging, and effective. The activities described in this paper were conducted with the aim of leading the DigiRescueMe project to improved learning outcomes, increased engagement, and cost savings. At the moment, the obtained results provide a very convincing basis, and it is hoped that they will be useful for the future development of the project and the activities that can be generated by it.

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Appendix A. Questionnaire on Risk Assessment

Dimensions

1. Terminology and definitions;
2. Risk management;
3. Risk analyses and methods.

Answers

1. Not at all;
2. A little;
3. So and so;
4. Enough;
5. A lot.

Demographic questions

1. Country (Where you actually work/study);
2. Region/City (Where you actually work/study);
3. Gender (M, F);
4. Education level (The highest study title you have (Diploma, Degree, Master, PhD, . . .));
5. School, University, Enterprise, Mine (Where you actually work/study);
6. Occupation (Rescue member, Teacher, Student, Miner, Engineer, . . .);
7. Length of service (How many years (for the workers)).

Items

	About Risk Assessment. . .	Dimension
1	I can give a definition of the hazard at the workplace.	Terminology and definitions
2	I can identify various hazardous situations in my workplace.	Terminology and definitions
3	I can determine prevention measures that I should take into account related to hazard.	Terminology and definitions
4	After the identification of the hazardous situation, I know steps which I should follow.	Terminology and definitions
5	I can distinguish physical hazards from chemical hazards.	Terminology and definitions
6	I know the difference between hazard and risk.	Terminology and definitions
7	I can define what a risk is at the workplace.	Terminology and definitions
8	I can determine risky situations at my workplace.	Terminology and definitions

9	I can define a near miss at the workplace.	Terminology and definitions
10	I can give an example of a near miss.	Terminology and definitions
11	I know how to fill the near miss form at my workplace.	Terminology and definitions
12	I can create a near miss form at my workplace.	Terminology and definitions
13	I can define the accident at the workplace.	Terminology and definitions
14	I can distinguish workplace accidents from other types of accidents.	Terminology and definitions
15	While I am making a plan, I consider the PDCA Cycle.	Terminology and definitions
16	I know the process and steps of the planning for any risk assessment process.	Terminology and definitions
17	I think that teamwork may contribute to individual work in risk assessment process.	Terminology and definitions
18	I think that individual work may contribute to teamwork in risk assessment process.	Terminology and definitions
19	I can distinguish which hazard resources are related to man.	Terminology and definitions
20	I can distinguish which hazard resources are related to machine.	Terminology and definitions
21	I can distinguish which hazard resources are related to medium.	Terminology and definitions
22	I can distinguish which hazard resources are related to mission.	Risk management
23	I know which hazards are the riskiest at the workplace.	Risk management
24	I know the control hierarchy.	Risk management
25	I know the principles of the risk assessment at the workplace.	Risk management
26	I am aware of the benefits of risk assessment for my workplace.	Risk management
27	I know how to define risk management steps at the workplace.	Risk management
28	I know when I should carry out the risk assessment at the workplace.	Risk management
29	I know when I should repeat the risk assessment at the workplace.	Risk management
30	I know the revision process of risk assessment at the workplace.	Risk management
31	I know the international legislation about occupational health and safety at the workplace.	Risk management
32	I know the national legislation about occupational health and safety at the workplace.	Risk management
33	I can classify the risk assessment methods.	Risk analyses and methods
34	I can make a comparison between qualitative and quantitative risk assessment methods.	Risk analyses and methods
35	I can detect the right risk assessment method for my workplace.	Risk analyses and methods
36	I know which members are included in a risk assessment team.	Risk analyses and methods
37	I know the roles of the members in a risk assessment team.	Risk analyses and methods
38	I can determine the dangerous risks at the workplace.	Risk analyses and methods
39	I can sort of the risks from the most dangerous one to least one.	Risk analyses and methods
40	I know how to implement Fine-Kinney Method.	Risk analyses and methods
41	I know how to implement John-Ridley Method.	Risk analyses and methods
42	I know how to implement HAZOP Method.	Risk analyses and methods
43	I know how to implement What If Method.	Risk analyses and methods

Appendix B. Questionnaire on Mine Rescue

Dimensions

1. Basic information;
2. Formal law aspects of rescuing;
3. Structure of rescue;

4. Sorts and organization of rescue activities;
5. Equipment used in rescue;
6. Hazard classification;
7. Natural hazards;
8. Ergonomic, organizational, and human factor risks;
9. Technical hazards;
10. Methods of prevention.

Answers

1. Not at all;
2. A little;
3. So and so;
4. Enough;
5. A lot.

Demographic questions

1. Country (Where you actually work/study);
2. Region/City (Where you actually work/study);
3. Gender (M, F);
4. Education level (The highest study title you have (Diploma, Degree, Master, PhD, . . .));
5. School, University, Enterprise, Mine (Where you actually work/study);
6. Occupation (Rescue member, Teacher, Student, Miner, Engineer, . . .);
7. Length of service (How many years (for the workers)).

Items

	About Mine Rescue. . .	Dimension
1	I know what occupational health and safety is.	Basic information
2	I know what mine rescue involves.	Basic information
3	I can distinguish between a rescue team and a rescue squad.	Basic information
4	I know what natural hazards in mining are.	Basic information
5	I know what technical hazards in mining are.	Basic information
6	I know the basic legal acts on the mining activity.	Formal law aspects of rescuing
7	I know the basic legal acts on the mine rescue.	Formal law aspects of rescuing
8	I know who supervises and controls mine rescue at mining facilities.	Structure of rescue
9	I know who is responsible for the condition of mine rescue at a mining plant.	Structure of rescue
10	I know what a mine rescue plan is.	Structure of rescue
11	I know the organizational structure of mine rescue services.	Structure of rescue
12	I know the basic tasks of the services and organizations that deal with the mine rescue.	Structure of rescue
13	I know what tasks are performed by the manager of the rescue operation.	Structure of rescue
14	I know the signals used in the mine rescue.	Sorts and organization of rescue activities
15	I know what escape routes are in mines.	Sorts and organization of rescue activities
16	I can indicate the basic equipment of the rescue squad on duty.	Equipment used in rescue
17	I can identify the basic equipment of the rescue base.	Equipment used in rescue
18	I know what the preventive works performed by mine rescuers are.	Sorts and organization of rescue activities

19	I can identify the types of rescue operations carried out in mining plants.	Sorts and organization of rescue activities
20	I know how a rescue operation should be managed.	Structure of rescue
21	I know the responsibilities of mine plant managers and supervisors involved in rescue operations.	Structure of rescue
22	I can identify the equipment used in mine rescue depending on the hazard that occurs in a particular rescue operation.	Equipment used in rescue
24	I know what medical equipment a rescue team should have access to.	Equipment used in rescue
25	I know the types of fire extinguishers used in the mine rescue.	Equipment used in rescue
26	I can distinguish between the different divisions of hazards used in mining operations.	Hazard classification
27	I know the difference between hazardous, harmful and annoying factors of the work environment.	Hazard classification
28	I can make a distinction between hazards in the working environment due to the nature of the impact of the factor.	Hazard classification
29	I can identify natural hazards that occur in mining due to the nature of the hazard.	Hazard classification
30	I know what a methane hazard is.	Natural hazards
31	I know the causes of methane hazard in mines.	Natural hazards
32	I know the classification of methane hazard.	Hazard classification
33	I know the basic methods of prevention of methane hazard.	Methods of prevention
34	I know what coal dust explosion hazard is.	Natural hazards
35	I know the causes of coal dust explosion hazard.	Natural hazards
36	I know the classification of coal dust explosion hazard.	Hazard classification
37	I know the basic methods of prevention of coal dust explosion hazard.	Methods of prevention
38	I know what the danger of endogenous fires is.	Natural hazards
39	I know the reasons for the occurrence of endogenous fire danger.	Natural hazards
40	I know the classification of the danger of endogenous fires.	Hazard classification
41	I know the basic methods of prevention of endogenous fire danger.	Methods of prevention
42	I know what climatic hazard is.	Natural hazards
43	I know the causes of climatic hazard.	Natural hazards
44	I know the classification of climatic hazard.	Hazard classification
45	I know the basic methods of prevention of climatic hazard.	Methods of prevention
46	I know what radiation hazard is.	Natural hazards
47	I know the causes of the occurrence of radiation hazard.	Natural hazards
48	I know the classification of radiation hazard.	Hazard classification
49	I know the basic methods of prevention of radiation hazard.	Methods of prevention
50	I know what the danger of roof fall.	Natural hazards
51	I know the causes of the danger of roof fall.	Natural hazards
52	I know the basic methods of prevention of roof fall	Methods of prevention
53	I know what the danger of tremors and quakes.	Natural hazards
54	I know the reasons for the occurrence of tremors and quakes.	Natural hazards
55	I know the classification of tremors.	Hazard classification
56	I know the basic methods of prevention of tremors.	Methods of prevention

57	I know what the hazard of gas and rock outbursts is.	Natural hazards
58	I know the reasons for the occurrence of gas and rock outbursts hazard.	Natural hazards
59	I know the classification of the hazard of gas and rock outbursts.	Hazard classification
60	I know the basic methods of prevention of the danger of gas and rock outbursts.	Methods of prevention
61	I know what a water hazard is.	Natural hazards
62	I know the causes of water hazard.	Natural hazards
63	I know the classification of water hazard.	Hazard classification
64	I know the basic methods of water hazard prevention.	Methods of prevention
65	I know the classification of the most important hazards that are present in surface mining.	Hazard classification
66	I can identify the most important hazards occurring in surface mining.	Hazard classification
67	I know the prevention of the most important hazards occurring in surface mining.	Hazard classification
68	I can indicate the most important technical hazards occurring in underground mining due to workplaces.	Technical hazards
69	I can identify the most important technical hazards occurring in surface mining due to workstations.	Technical hazards
70	I know what ergonomic hazards are.	Ergonomic, organizational, and human factor risks
71	I can identify the most important ergonomic hazards occurring in mining workstations.	Ergonomic, organizational, and human factor risks
72	I know what organizational hazards are.	Ergonomic, organizational, and human factor risks
73	I can identify the most important organizational hazards that occur at mining workplaces.	Ergonomic, organizational, and human factor risks

Appendix C. Questionnaire on Mental Wellbeing

Dimensions

1. Basic information;
2. Risks for work-related stress;
3. Stress reactions;
4. Stress factors;
5. Sentinel events.

Answers

1. Strongly disagree;
2. Disagree;
3. I don't know;
4. Agree;
5. Strongly agree.

Demographic questions

1. Country (Where you actually work/study);
2. Region/City (Where you actually work/study);
3. Gender (M, F);
4. Education level (The highest study title you have (Diploma, Degree, Master, PhD, . . .));
5. School, University, Enterprise, Mine (Where you actually work/study);
6. Occupation (Rescue member, Teacher, Student, Miner, Engineer, . . .);
7. Length of service (How many years (for the workers)).

Items

	About Mental Wellbeing...	Dimension
1	I can define the most important psychosocial hazards in the work environment.	Basic information
2	I know the preventive measures related to psychosocial hazards occurring in the work environment.	Basic information
3	Risks for work-related stress are related to the use of new forms of employment contracts.	Risks for work-related stress
4	Temporary contracts and the uncertainty and insecurity of the job itself is a risk for work-related stress.	Risks for work-related stress
5	An increasingly aging workforce is a risk for work-related stress.	Risks for work-related stress
6	The lack of adequate turnover is a risk for work-related stress.	Risks for work-related stress
7	High workload is a risk for work-related stress.	Risks for work-related stress
8	Pressure on workers by management is a risk for work-related stress.	Risks for work-related stress
9	High emotional tension is a risk for work-related stress.	Risks for work-related stress
10	Violence and harassment at work is a risk for work-related stress.	Risks for work-related stress
11	Interference of private life in the work is a risk for work-related stress.	Risks for work-related stress
12	Imbalance between work and private life is a risk for work-related stress.	Risks for work-related stress
13	Harmful physical reactions to job demands are signals of work-related stress.	Stress reactions
14	Harmful emotional reactions to job demands are signals of work-related stress.	Stress reactions
15	Work related stress can be raised when job demands are not commensurate with the skills, resources or needs of workers.	Stress factors
16	Work related stress can be raised when people perceive an imbalance between the demands made on them and the resources available to them to meet those demands.	Stress factors
17	Stress is a situation of prolonged tension at work.	Stress factors
18	Stress can reduce efficiency at work and lead to poor health.	Stress reactions
19	Work-related stress can be caused by the content of the job.	Stress factors
20	Work-related stress can be caused by inadequacy in the management of the work organization.	Stress factors
21	Work-related stress can be caused by inadequacy in the management of the working environment.	Stress factors
22	Work-related stress can be caused by shortcomings in communication.	Stress factors
23	Work-related stress is a condition that can be accompanied by physical disorders.	Stress reactions
24	Work-related stress is a condition that can be accompanied by psychological disorders.	Stress reactions
25	Work-related stress is a condition that can be accompanied by social dysfunctions.	Stress reactions
26	Work-related stress is a consequence of the fact that some individuals do not feel capable of responding to the requests or expectations placed on them.	Stress factors
27	The work environment is one of the factors that cause work-related stress.	Stress factors
28	The equipment is one of the factors that cause work-related stress.	Stress factors
29	The workloads and rhythms are factors that cause work-related stress.	Stress factors
30	The role of the organization is one of the factors that cause work-related stress.	Stress factors
31	The decision-making autonomy and control are one of the factors that cause work-related stress.	Stress factors
32	The legal responsibility inside an organization is one of the factors that cause stress.	Stress factors
33	Interpersonal conflicts at work are factors that cause work-related stress.	Stress factors
34	The career evolution and development are one of the factors that cause work-related stress.	Stress factors

35	Accident rates are sentinel events of work-related stress.	Sentinel events
36	The absence due to illness is one of the sentinel events of work-related stress.	Sentinel events
37	The turnover is one of the sentinel events of work-related stress.	Sentinel events
38	The number of proceedings and sanctions is one of the sentinel events of work-related stress.	Sentinel events
39	The number of reports to the competent doctor is one of the sentinel events of work-related stress.	Sentinel events
40	The specific and frequent formalized complaints by workers are sentinel events of work-related stress.	Sentinel events
41	Accident rates are sentinel events of work-related stress.	Sentinel events
42	The malaise of a worker results from his/her poor identification with the group or organization to which he/she belongs to.	Sentinel events
43	The malaise of a worker results from his/her low job satisfaction.	Sentinel events
44	The malaise of a worker results from his/her low confidence in the organization and the consideration of wanting to leave his/her job.	Sentinel events

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Article

Children's Online Safety: Predictive Factors of Cyberbullying and Online Grooming Involvement

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Abstract: The increase in the use of the Internet, strongly boosted by the spread of COVID-19, has amplified the risk of involvement in cyberbullying and online grooming among minors. To date, most research on these phenomena has focused on middle and high school students, with fewer studies on younger children. The present study aims to fill this knowledge gap by measuring the spread of cyberbullying and online grooming in a sample of 410 primary school students in the city of Rome and by identifying the main individual and environmental predictors associated with the involvement of children in these phenomena using factor analysis. Results indicate that both cyberbullying and online grooming are widespread among respondents, showing common traits within the four latent dimensions identified. Screen time is among the main predictors of children's involvement, together with parental supervision, phubbing behaviours, prosocial tendencies and family socio-economic background. These findings highlight the need for further studies on representative samples of this age group, as well as for a greater cooperative effort among schools, parents and caregivers to keep children safe in the virtual world.

Keywords: cyberbullying; children; online grooming; screen time; predictors; social deviance

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1. Introduction

The shift from the offline world to the virtual sphere has faced an unpredictable acceleration over the last few years. The physical distancing experienced by most of the worldwide population to limit the spread of COVID-19, together with the increasing availability of digital devices, has made the Internet even more pervasive in everyone's lives, especially for the youngest population. During the closure of most schools and with distance teaching, the Internet has played a crucial role in children's lives as it was the only possible way to keep on studying and to maintain any kind of extra domestic relationship. In Italy, according to the Italian National Institute of Statistics (ISTAT), between 2019 and 2021, the percentage of children aged between 6 and 10 using the Internet has increased from 62.5% to 89.1%, with significant growth of almost 30% of Internet daily users [1]. This unprecedented use of digital devices among children, often without sufficient parental supervision, has magnified the risks arising from exposure to cyberspace [2,3]. Even though nowadays children become familiar with digital devices at a very early age, they often lack the skills and the cognitive abilities to recognise dangerous content and non-authoritative sources. According to the finding of a study coordinated by the Joint Research Centre of the European Commission, with data from eleven European countries collected between June and August 2020, Italy was among the highest ranked in terms of increase in cyberbullying victimisation rates and in the exposure of children to gory or violent content during the COVID-19 spring lockdown [4]. For this reason, in recent years, research interest in cyberbullying is growing and studies attempting to measure its spread [3,5], to identify the main risk and protective factors [6–8] and to study its psychophysical consequences compared to those of traditional bullying [9,10] have proliferated. However, the different definitions adopted by researchers and, consequently, the variety of measurement tools and research methodologies employed have often led to inconsistent results.

The scientific debate on the definition of cyberbullying is still open between those who consider it the virtual version of traditional bullying [11] and those who instead look at it as a completely distinct phenomenon, due to the peculiar characteristics of the virtual world [12]. Starting from the definition of traditional bullying that includes "aggressive, intentional acts carried out by a group or an individual repeatedly and overtime against a victim who cannot easily defend him or herself" [13], we can identify its main elements as follows: the intent to harm, the repetition, and the imbalance of power between the victim and the perpetrator [14]. However, these characteristics do not apply to cyberbullying in the same way, as the virtual sphere has different potentialities. To date, a widely accepted definition of cyberbullying is the one that describes it as "using information and communication technologies (ICT) to repeatedly and intentionally harm, harass, hurt and/or embarrass a target" [15]. First of all, the characteristic that distinguishes cyberbullying from bullying is the concept of repetition, which, in the virtual world, depends not only on the length of time during which texts, images or videos remain online but also on how many users they reach. In fact, web content can become viral if shared on social media platforms by popular profiles and its deletion can be very difficult. Secondly, the imbalance of power may exist in the availability of technologies, but it is minimised by the possibility of anonymity. This latter element encourages those perpetrators who would not adopt the same abusive behaviours in offline interactions, together with a lower perception of potential repercussions and punishment, and leads to the so-called online disinhibition effect [16,17]. For this reason, cyberspace offers more chances for overlapping between the roles of victims and actors than in the face-to-face sphere, as the Internet can be the perfect channel to take revenge for any abuse suffered offline. Thus, a focus on the bully–victim role is crucial in the analysis of the cyberbullying phenomenon. Indeed, children and adolescents belonging to this dual category are the most at risk of vulnerability since they are the most rejected by peers, suffering double negative consequences [18–20]. Finally, according to a large body of literature about the cyberbullying impacts, the potentially infinite audience and the anonymity of the virtual sphere make this phenomenon more harmful than traditional bullying in terms of consequences, including higher levels of depression, stress, anxiety, suicidal ideas and attempts, self-harm and worse physical health [21–27].

To better understand the complexity of the phenomena under observation, the adoption of a socio-ecological approach [28] is needed because it allows us to consider all the relevant factors related to both the individual sphere (such as sex, age, time spent in front of a screen, prosociality and perceived emotions) and the social context (socio-economic context, school climate, parental education and parental employment status) [29]. Concerning the gender differences in cyberbullying involvement, the results of the scientific literature are quite inconsistent: some studies have found that the prevalence rates of cyber victimisation are higher among girls than among boys [30–32], others suggest that boys have a higher probability of being perpetrators [33–37], while most of the studies have not found any significant correlation between gender and the prevalence rates of cyberbullying [38,39]. In a similar way, the relationship between the involvement in cyberbullying and sport practice, which has been investigated only by a few studies, shows inconclusive results. Although some studies have found that physical activity has a protective role in both cyber victimization and perpetration due to its positive effects on psychological well-being and self-esteem [40], others have not found any significant relationship between the phenomena [41–43]. In this regard, other studies reveal that in the absence of a specific teaching approach, sport practice does not protect young people from social conditioning or exclusion [44]. Moreover, exposure to violent video games has also been taken into account in several studies with ambivalent results. Many of these studies have found positive significant associations between prolonged exposure to video games with violent content and cyberbullying involvement [45–47], while others have not found meaningful correlations [48].

According to recent literature reviews, the main predictors associated with cyber victimisation are as follows: high levels of time spent online, scarce empathy and prosociality, low self-esteem, high levels of anxiety and loneliness, traditional bullying victimisation, low socio-economic status, scarce parental supervision on children's online activities and negative school climate [49]. On the other hand, the main predictive factors of cyber perpetration are high levels of time spent online, low self-esteem, scarce empathy and prosociality, tendency to aggressive behaviours, high levels of anger, traditional bullying victimisation, peer rejection, scarce parental supervision on children's online activities and negative school climate [7,8]. Thus, as the literature review shows, predictors of cyberbullying victimization and perpetration often overlap in identifying highly vulnerable groups, which should be the primary target of the intervention programs supporting youth well-being.

Along with the increase in cyberbullying, another dangerous consequence of the rise in the use of the Internet among children is the increasing risk of online grooming perpetrated by adult strangers. In Italy, this phenomenon has reached its highest levels during the last two years, particularly involving children under the age of 13 [50]. The considerable boost in complaints of child pornography and grooming that has been recorded is probably linked to the efficacy of the numerous awareness and information campaigns implemented regarding these issues, even if the real prevalence of this phenomenon is still unknown. The term "online grooming", used for the first time by Salter [51], refers to a manipulative process in which the groomer, using online platforms, builds up a trusting and emotional relationship with a minor with the purpose of sexual abuse or exploitation. In recent years, due to the unprecedented rise in Internet use among children and adolescents mentioned above, this phenomenon has become a growing problem and studies on the main risk factors are proliferating [52–54]. As is widely reported by the literature, family support, especially in terms of parental monitoring of minors' online activities, is a strong deterrent to involvement in this dangerous process, while time spent on the Internet increases the risk of victimisation [55–57].

Although most studies on cyberbullying and online grooming have been conducted on middle and high school students [8,54,58], the age of people involved in these phenomena is progressively decreasing [4]. For this reason, research on the spread of cyberbullying and online grooming among primary school children has become ever more urgent, considering also that involvement in these phenomena at an early age represents a serious risk of victimisation during adolescence and adulthood [59,60]. Furthermore, a deeper understanding of these phenomena through the collection of reliable data can allow policymakers to design and implement effective prevention programs for children's online safety.

The present study, which is based on a survey carried out in Rome on primary school children, fits into this framework with the main purposes of assessing the spread of cyberbullying and online grooming among primary school students and identifying the main individual and environmental predictors associated with the involvement of children in these phenomena. Detecting the main predictive factors of children's involvement in cyberbullying and online grooming allows us to confirm or reject the findings of the scientific literature mainly based on a sample of adolescents and pre-adolescents representing a crucial point for the implementation of preventive intervention programs.

Starting from the main findings of the scientific literature reviewed above, we formulate the following hypothesises:

H1. *The involvement of children in cyberbullying increases as their age increases.*

H2. *Children most at risk of involvement in both cyberbullying perpetration and victimisation are those with high levels of screen time, low socio-economic family backgrounds, living in more disadvantaged social contexts, with scarce parental supervision on their online activities, along with those who prefer videogames with violent content, and children with scarce relational competencies and high levels of emotional discomfort.*

H3. *Children more at risk of involvement in online grooming victimisation are those with the highest level of screen time, high levels of emotional discomfort, low parental monitoring of their online activities, and those who belong to the most vulnerable categories from a socio-economic point of view.*

H4. *Sport practice is not a significant variable for the involvement in these phenomena.*

2. Materials and Methods

2.1. Data Collection and Sample

This study shows the results of a survey carried out in Rome during the Spring of 2021, between April and May, on 410 children attending the last three years of primary school, aged 8–11. Eight primary schools, four located in the 6th district and the other four in the 8th districts [1], were involved in the study. The choice of these two territories, which differ in their socio-economic characteristics, allows the formulation of hypotheses that can be extended to other similar contexts and to verify the influence of the socioeconomic context on online behaviours. In particular, the 6th district of Rome, which is the most populated and the youngest in terms of demographic structure, is characterised by high levels of poverty from a socio-economic point of view, while the 8th district is less populated, the oldest of the city, and with better socio-economic conditions [61]. For each selected school, 3 classes—third, fourth and fifth grade—were randomly selected with cluster sampling to obtain a two-stage stratified sample with stratification of the first-stage units (schools) and random selection of the second-stage units (classes of students). Therefore, the sample is probabilistic and representative of the two involved districts, while it cannot be considered representative of the national territory. Interviews were conducted using a structured paper questionnaire with the assistance of two researchers in order to collect data as reliable as possible. In fact, the physical presence of researchers within the classrooms and their constant assistance to the participants ensured a better understanding of the questions among respondents, but it also minimised the interference of teachers and the school environment. Furthermore, due to the young age of the respondents, special attention was paid to the formulation of the questions and also to the type and the size of the font in designing the paper questionnaire. The main obstacle to the implementation of the survey was the physical access to the schools since the administration phase was carried out during the spread of the COVID-19 pandemic. However, it was overcome thanks to the awareness of the school administrations that recognised the importance and the urgency of the research.

In total, 410 children were interviewed. Of these, 46.3% (190) were females and 53.7% (220) were males, 35.4% (145) were attending the 3rd grade, 31.7% (130) the 4th grade and 32.9% (135) the 5th grade. Among the respondents, 86.1% (342) have parents with Italian citizenship, while 13.9% (55) have at least a parent with foreign citizenship (8.3% (33) have both foreign parents). Furthermore, 47.6% (195) attended a school located in the 6th district, while 52.4% (215) were in the 8th district. The questionnaire consists of 42 questions covering the following main topics: cyberbullying perpetration and victimisation, online grooming victimisation, time spent in front of a screen (screen time), quantity and quality of social interaction among peers, adherence to gender roles, emotional well-being and prosociality. Attached to the request for the consent, a short questionnaire on socio-demographic information about the respondents' families was administered to each parent. In this way, we collected data about the number of family members, the number of cohabiting and non-cohabiting brothers and sisters of respondents, and also the citizenship, marital status, educational qualification, and employment status of their parents. These socio-demographic forms were associated with the children's questionnaires through a numeric code, in order to guarantee the anonymity of the collected data.

2.2. Materials

To study cyberbullying victimisation, we included in the questionnaire a multiple-response question about actions suffered online during the year prior to the survey. It comprised the following list of actions: being insulted or mocked, being threatened, being excluded, being incited to injure themselves, and being a victim of the sharing of personal photos or videos without consent. In a similar way, to examine online grooming victimisation, respondents were asked if they had suffered at least one of the following online actions performed by adult strangers: receiving compliments, gifts offer, photos or videos, questions about their clothing, requests for personal photos or videos and requests for face-to-face meetings. Finally, to investigate cyberbullying perpetration, the same technique has been used and the multiple-response question included the following list of actions carried out online during the year prior to the survey: venting anger online, insulting someone, teasing someone, stimulating online quarrels, threatening someone, excluding someone from a group, sharing photos or videos of other people without their consent, inciting someone to injure him/herself. To assess the prevalence rates of these phenomena, we defined victims or actors of cyberbullying as those children who had suffered or carried out at least one of the proposed actions. In the same way, children who had suffered at least one of the proposed online grooming actions were defined as victims of online grooming.

To better understand the complex and multidimensional phenomena of cyberbullying and online grooming among children, other specific variables concerning the socio-economic family background in terms of parental educational level and employment status were also taken into account. The parental educational level indicator was built starting from the parents' educational qualification collected through the family consent form filled out by the parents. Considering, simultaneously, the answers of both parents, these were synthesised in the indicator, identifying 2 levels of parental education: medium–low and medium–high. In the same way, the parental employment status indicator was built through a question about current employment situations. The outcome of the recording process was a 2-level employment status indicator: medium–low and medium–high.

To measure the time spent in front of a screen, two indicators were built starting from the time spent playing video games and that spent using social media and applications. The frequency of exposure was detected in days per week and hours per day. The outcomes of the recording process were the two screen-time indicators, one on videogames and one on social media and applications, which identify four levels of screen time: absent, low, medium and high. Respondents with high levels of screen time, or children spending at least two hours per day on videogames, social media and applications, were considered hyper-connected children.

With the aim to collect data about parental awareness of children's online activities, respondents were asked if their parents knew the videogames, social media and applications that they commonly use. The results of the recording process are two indicators, one on the parental awareness about videogames and one on the parental awareness about social media and applications used by respondents, which identify the presence or absence of parental monitoring of children's online activities.

Another indicator related to Internet addiction concerns the discomfort associated with the impossibility of using digital devices for a week; respondents were asked to indicate their potential reaction among the following list: anxiety, sadness, boredom, calm, isolation, and indifference. The collected answers were dichotomised between the presence and absence of discomfort.

To study the phenomenon of phubbing, which is literally the act of snubbing someone in a social environment by concentrating on one's phone instead of talking to the person directly [62], children were asked to indicate how often they prefer to use their devices instead of enjoying the presence of other people on 4-point scales from "never" to "always". The collected answers were dichotomised during the recording process between never/sometimes and often/always.

Finally, the present study also considered the prosociality of children, which is the tendency to adopt helping behaviours towards others without external rewards [63]. In this case, a specific indicator was built starting from the results of three questions about the utility of understanding the other's feelings, the way to compliment a friend, and the way to understand how a friend feels. For each of these questions, respondents had four possible answers linked to the presence of prosocial tendencies, a neutral behaviour, a self-centred tendency, and indifference. Synthetising the scores, a single indicator was built with 3 levels of the tendency to adopt prosocial behaviours: low, medium, and high.

To study the emotional well-being of the respondents, a question about the frequency of the perception of specific negative primary emotions was included in the questionnaire. The emotions proposed were anger, sadness, loneliness, fear and anxiety. Respondents were asked to indicate the frequency in the perception of all the above emotions on a 4-point scale from "never" to "always". The collected answers were dichotomised during the recording process between never/sometimes and often/always.

2.3. Data Analysis

The data analysis was carried out following two steps: a bivariate analysis and a factor analysis. The process started from a bivariate statistical analysis carried out using SPSS software (version 26 server) (IBM, Chicago, IL, USA) [64] to measure the prevalence rates of cyberbullying victimisation and perpetration and the online grooming victimisation among children, and also to explore the relationships between these phenomena and screen time. A second step concerned the implementation of the factor analysis technique using R software [65], with the aim of studying the latent dimensions of the phenomena covered by the survey and investigating the relationships between them and other individual and environmental variables to identify the main predictive factors associated with the involvement of children in cyberbullying and online grooming.

Factor Analysis

The factor analysis technique was implemented by using R software with the aim of studying cyberbullying and online grooming among children and identifying the latent dimensions of the data collected. The resulting factors can be considered as a set of indicators that allows us to explore the relationships between the phenomena and other individual and environmental variables starting from the main findings of the scientific literature reviewed above. This phase of data analysis started with the imputation of the missing values. In particular, Multivariate Imputation by Chained Equations [66–68] was used; the choice was made mainly due to two important reasons. On the one hand, mice imputation creates multiple imputations for multivariate missing data: in this way, it is possible to take into account the uncertainty due to missingness; in our analysis, for each missing value, we let the number of imputations be equal to 5 and then, in order to build the final imputed dataset, we kept the value that was the most frequent among those 5 imputed. On the other hand, mice imputation allows us to take into account most of the available information: indeed, it imputes every missing value in each specific column by using a separate model, which includes all the other variables in the dataset as covariates.

To carry out the factor analysis, we, firstly, selected the variables of interest: variables related to cyberbullying victimisation and perpetration, those related to online grooming victimisation perpetrated by adult strangers, and also the two indicators concerning the screen time on videogames and the screen time on social media and applications. Then, since those variables are either binary or categorical, we computed the polychoric correlation between each pair of variables using the *hetcor* function in the *polychor* R package [69,70], which allows us to compute correlations for these kinds of data.

By using the Kaiser–Meyer–Olkin and Bartlett's tests (functions KMO and *cortest.bartlett* in the *psych* R package [71,72], we realized that factor analysis is well suited for our data. Indeed, the Kaiser–Meyer–Olkin tests returned an overall value of Measure of Sampling Adequacy (MSA) above 0.7, meaning that the variables are adequate for factor analysis [73];

moreover, Bartlett's test result was significant, meaning that the correlation matrix has significant correlations among at least some of the variables in a dataset, a prerequisite for factor analysis to work. Given that factor analysis is well suited for our data, we implemented factor analysis (function *factanal* in the *stats* R package) [74], by letting the number of factors range in [2,10]. In this way, by using the scree plot (number of factors vs. resulting eigenvalue) and the elbow method, we realized that the optimal number of factors is seven; although, a better interpretation of the results is reached by using only four factors, which still achieve good performance in terms of explained variance. As Figure 1 shows, the elbow is observed when the number of factors is 7. However, by analysing the factor loadings, we observed that the results obtained by choosing 4 factors provide a deeper and better interpretation. In this way, the small loss in explained variance (from 86% to 76%) is fully compensated by the gain in statistical and sociological interpretability.

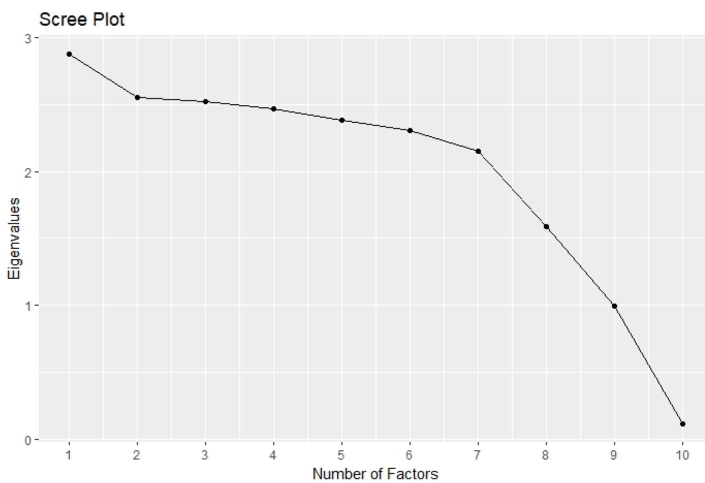

Figure 1. Scree plot.

Once the factor analysis has been implemented, factor scores were studied in order to fully identify the four latent dimensions. To better understand what the four factors describe, we, firstly, considered the factor loadings to study to what extent each variable contributes to defining each factor. Moreover, we also considered additional individual and environmental variables, which will be listed in Section 3.2. By using these variables, we implemented two different analyses driven by two different motivations: on the one hand, to study how the distribution of factors' scores changes according to the variables, we carried out the analysis of the variance (ANOVA). The ANOVA allowed us to study how the factor scores are distributed with respect to the structural, individual, and environmental variables. Among the most significant results, we will recall only some of them for each of the factor's distribution in Section 3. On the other hand, to compare differences in relevant statistics of central tendency, we computed the summary statistics (i.e., mean, median, min, max, range) of each factor. In the present study, we will show only the mean scores for an easier presentation of the results. We highlight that, in order to make a comparison among the factor scores and to obtain a measure easier to understand at the individual level, the range was converted on a scale between 0 and 100; the value calculated for each child represents the individual measure of the latent dimension. Therefore, the average value of each factor represents the average of the individual measures. In this way, it is possible to calculate the average value of each latent factor within subgroups, identifying the characteristics of the respondents with higher scores. A detailed description of the four obtained factors, which considers the factor loadings and the mean scores per subgroups of categorical variables, is given in Section 3.

3. Results

3.1. Bivariate Analysis

Figure 2 shows the prevalence rates of cyberbullying among respondents, identifying cyberbullying victims, cyberbullying perpetrators and online-grooming victims. About three out of ten children have been actors of at least one cyberbullying action during the year prior to the survey without significant differences between boys and girls, while two out of ten respondents have been victims of at least one of these actions, especially boys. The online grooming perpetrated by adult strangers affected more than one in ten children during the year prior to the survey, with no significant differences between girls and boys.

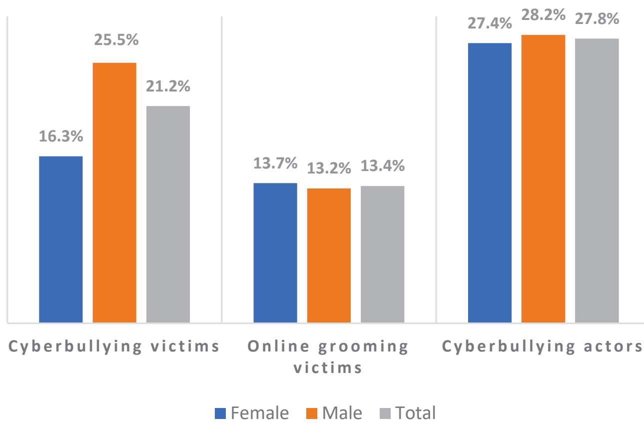

Figure 2. Prevalence rates of cyberbullying perpetration and victimisation and online grooming victimisation by sex.

To investigate the relationship between the involvement in both cyberbullying and online grooming and the time spent in front of a screen, it is important to look at the sample distribution among the levels of the indicators of screen time playing videogames and using social media and applications. According to the indicator of screen time on videogames, only 6.6% of children do not use videogames (9.6% of girls and 4.1% of boys), 37.1% shows a low level of screen time (45.7% of girls and 29.7% of boys), 30.0% a medium level (30.3% of girls and 29.7% of boys) and the remaining 26.3% of the sample shows a high level of screen time on videogames with a significant prevalence of boys (36.5% and 14.4% of girls). Concerning the screen time indicator on social media and applications, 15.7% of respondents do not use these platforms (14.3% of girls and 17.0 of boys), while 35.1% shows a low level of screen time (37.6% of girls and 33.0% of boys), 29.7% a medium level (32.8% of girls and 27.1% of boys) and the remaining 19.4% shows a high level of screen time on social media and applications (15.3% of girls and 22.9% of boys). As mentioned before, respondents with a high level of screen time were considered hyper-connected. Among these hyper-connected children, results show the highest percentages of involvement in cyberbullying as victims (36.4% and 38.0%) and actors (38.3% and 43.0%), as well as in online grooming as victims (21.5% and 24.1%).

3.2. Factor Analysis

In this paragraph, the four factors obtained through the factor analysis will be described considering the contribution of each variable to each factor (Table 1). Furthermore, the mean scores of the factors will be analysed in relation to the following structural variables: sex, grade, district, parental education, parental employment status and parental citizenship. Lastly, the mean scores related to the following variables and indicators will also be analysed: parental supervision of videogames, parental supervision on social media and applications, phubbing behaviours, the enjoinment in attending school, peer interaction, discomfort associated with the impossibility of using digital devices, prosociality, violent videogames, sport practice and negative emotions.

Table 1. Factor loadings for input variables.

	Factor 1	Factor 2	Factor 3	Factor 4
Venting anger online	−0.061	−0.061	0.862	0.163
Excluding someone from a group	0.193	0.548	0.671	0.12
Teasing someone	0.404	0.476	0.316	0.568
Insulting someone	−0.063	0.359	0.324	0.83
Sharing photos or videos of other people without their consent	0.29	0.77	0.155	0.05
Threatening someone	−0.376	0.517	0.448	0.534
Inciting someone to injure him/herself	−0.16	0.025	0.077	−0.099
Receiving gifts offered by adult strangers	−0.534	0.506	0.349	0.173
Receiving compliments from adult strangers	0.291	0.038	0.664	0.24
Receiving requests for face-to-face meetings from adult strangers	0.887	0.103	0.042	0.434
Sending photos or videos to adult strangers	0.867	0.15	0.208	−0.278
Receiving questions about your clothing from adult strangers	−0.169	−0.944	0.141	0.101
Receiving photos or videos from adult strangers	0.81	0.146	−0.221	0.046
Being incited to injure yourselves	−0.16	0.025	0.077	−0.099
Being insulted or mocked	0.331	0.589	0.342	−0.062
Being threatened	−0.011	0.319	0.28	−0.885
Being excluded from a group	0.277	0.006	0.487	−0.153
Being victim of the sharing of personal photos or videos without consent	−0.127	0.039	−0.199	−0.524
Screen time on videogames	0.494	0.039	0.15	0.038
Screen time on social media and applications	0.657	0.288	0.126	0.088

Factor 1: Hyperconnection and online grooming victimisation. As mentioned in the methodology, to better understand to what extent each variable has contributed to the definition of this latent dimension, we have considered the factor loadings related to all the input variables (Table 1). In this case, those related to screen time on videogames and on social media and applications showed the highest scores, as well as the loadings related to the following three variables regarding online grooming victimisation: receiving photos or videos from adult strangers, sending photos or videos to adult strangers, and receiving a request for a face-to-face meeting from adult strangers. As Table 2 shows, the mean score of this first factor is 50.29 and higher scores were recorded among boys compared to girls and in older children. Looking at the other structural variables, the data show slightly higher scores among children with Italian parents, with a medium–low parental educational level and a medium–low parental employment status. Furthermore, the analysis of other relevant variables and indicators shows that the children most involved in this phenomenon are those with scarce parental supervision on their online activities, especially on those related to social media and applications; those who prefer violent videogames; those with a higher tendency to adopt phubbing behaviours and to argue with friends; those who do not enjoy attending school; those who would feel discomfort without the possibility of using digital devices for a week; those with low and medium levels of prosociality; and those with higher frequency in the perception of anger and sadness (Table 3). These results are in line with the analysis carried out by using the ANOVA model. For example, we realized that there is a statistically significant difference in average factor scores ($p < 0.01$) according to gender. In particular, on average, the factor score for males is 0.18 higher than the one

for females. Moreover, a statistically significance difference in the average factor scores is due to the children's ages. Indeed, on average, the factor score of the children in the 5th grade is 0.18 higher than the one for those in the 3rd grade ($p < 0.05$), and the factor score of children in the 4th grade is 0.13 higher than the one for younger children ($p < 0.1$).

Table 2. Factors' mean scores for structural variables.

		Factor 1	Factor 2	Factor 3	Factor 4
	Mean	50.29	51.65	56.92	35.87
Sex	Male	51.19	52.21	57.56	35.88
	Female	49.25	51.02	56.17	35.85
Grade	III	49.23	50.67	56.37	35.42
	IV	50.66	52.22	56.92	35.82
	V	51.07	52.18	57.50	36.40
District	6th	50.18	51.35	56.43	36.06
	8th	50.38	51.93	57.35	35.70
Parental education	Medium–low	51.12	52.35	57.45	36.45
	Medium–high	49.04	50.67	55.76	35.06
Parental employment status	Medium–low	51.08	52.25	57.08	36.53
	Medium–high	49.31	50.94	56.31	34.85
Parental citizenship	Italian	50.37	51.70	56.70	35.79
	Foreign	49.52	51.25	56.99	36.32

Table 3. Factors' mean scores for individual and environmental variables.

		Factor 1	Factor 2	Factor 3	Factor 4
	Mean	50.29	51.65	56.92	35.87
Parental supervision on videogames	Yes	50.29	51.49	56.70	35.57
	Not	51.43	52.53	58.19	36.87
Parental supervision on social and apps	Yes	50.73	51.75	57.03	36.05
	Not	53.02	53.84	59.89	37.03
Phubbing behaviours	Low frequency	49.19	51.13	56.25	35.38
	High frequency	52.48	52.66	58.25	36.52
Enjoinment in attending school	Positive	49.55	50.96	56.24	35.43
	Negative	53.18	54.40	59.42	37.48
Peer interaction	Positive	50.04	51.28	56.59	35.48
	Negative	52.16	54.00	59.14	38.20
Discomfort caused by the absence of digital devices	Yes	52.03	52.75	58.29	37.01
	Not	48.91	50.63	55.69	34.70
Prosociality	Low	50.90	53.86	58.49	35.30
	Medium	50.85	51.62	57.03	35.73
	High	49.58	50.90	56.25	36.20

Table 3. *Cont.*

		Factor 1	Factor 2	Factor 3	Factor 4
Violent videogames	Yes	52.94	53.42	59.19	37.13
	Not	49.63	51.22	56.35	35.56
Sport practice	Yes	50.32	51.75	57.20	36.17
	Not	50.63	51.52	56.03	34.85
Anger	Low frequency	49.55	51.03	56.17	35.45
	High frequency	53.90	54.61	60.36	37.73
Sadness	Low frequency	49.95	51.59	56.83	35.70
	High frequency	51.78	52.11	57.41	36.36
Loneliness	Low frequency	50.23	51.58	56.79	36.38
	High frequency	51.04	52.14	57.82	32.92
Fear	Low frequency	50.42	51.64	56.98	36.08
	High frequency	50.12	51.89	56.82	34.49
Anxiety	Low frequency	50.33	51.41	56.76	35.91
	High frequency	50.34	52.41	57.43	35.98

Factor 2: Direct cyberbullying perpetration and victimisation and online grooming victimisation. Looking at the factor loadings of each input variable, we can highlight that those related to the cyberbullying direct actions of sharing photos or videos without consent, excluding someone from a group and insulting or teasing someone, are the highest, as well as the loadings related to the variable "being insulted or mocked" and "receiving gifts offers by adult strangers". As Table 2 shows, the mean score of this second factor is 51.65 and higher scores were recorded among boys compared to girls. Looking at the other structural variables, the data show slightly higher scores among children with Italian parents, attending schools located in the 8th district, with a medium–low parental educational level and medium–low parental employment status. Furthermore, the analysis of the other relevant variables and indicators shows that children most involved in this phenomenon are those with no parental supervision on their online activities, especially on those related to social media and applications; those who prefer violent videogames; those with a higher tendency to adopt phubbing behaviours and to argue with friends; those who do not enjoy attending school; those who would feel discomfort if prevented from the use of digital devices for a week; and those with a low level of prosociality; and those with higher frequency in the perception of anger and anxiety (Table 3). These results are in line with the analysis carried out by using the ANOVA model. For example, there exist statistically significant differences according to gender and to the attitude of playing violent videogames. Notably, a statistically significant difference in the average factor scores ($p < 0.05$) according to gender is observed. In particular, on average, the factor score for males is 0.1 higher than the one for females. Moreover, the child who does not prefer violent videogames has on average a factor score 0.17 lower than the one for the children who prefer violent videogames ($p < 0.01$).

Factor 3: Indirect cyberbullying victimisation and perpetration and online grooming victimisation. In this case, the highest factor loadings are those related to the cyberbullying indirect action of social exclusion (both suffered and carried out), to the action of venting anger online, and also the one related to the online grooming variable of receiving compliments from adult strangers (Table 1). As Table 2 shows, the mean score of this third factor is 56.92 and higher scores are observed among boys compared to girls and among older respondents. Looking at the other structural variables, in this case, the data also show slightly higher scores among children attending schools located in the 8th district, with a medium–low parental educational level and a medium–low parental employment status, with no difference in relation to parental citizenship. Furthermore, the analysis of the other relevant variables and indicators shows that children most involved in this phenomenon are those with no parental supervision on their online activities, both in relation to videogames and to social media and applications; those who prefer violent videogames; those with a higher tendency to adopt phubbing behaviours and to argue with friends; those who do not enjoy attending school; those who would feel discomfort without the possibility of using digital devices for a week; those with a low level of prosociality; those who practice sport; and those with higher frequency in the perception of anger and loneliness (Table 3). These results are in line with the analysis carried out by using the ANOVA model. For example, a significant difference in the factor distribution is observed. Indeed, on average, children who always or often feel angry have a factor score 0.37 higher than those who do not or rarely feel angry ($p < 0.01$).

Factor 4: Cyberbullying perpetration. According to the factor loadings of each variable, this latent dimension mainly describes cyberbullying perpetration. Indeed, the highest scores are those related to the cyberbullying actions of insulting, teasing and threatening someone (Table 1). As Table 2 shows, the mean score of this fourth factor is 35.87 with little differences related to sex, age, parental citizenship and school district. Looking at the other structural variables, in this case, the data show slightly higher scores among children with a medium–low parental educational level and a medium–low parental employment status. Furthermore, the analysis of the other relevant variables and indicators shows that children most involved in this phenomenon are those with lower parental supervision on their online activities, both in relation to videogames and to social media and applications; those who prefer violent videogames; those with a higher tendency to adopt phubbing behaviours and to argue with friends; those with high levels of prosociality; those who do not enjoy attending school; those who would feel discomfort without the possibility of using digital devices for a week; and those who practice sport. In relation to the perception of negative emotions, higher scores were found with higher frequency in the perception of anger, and with lower frequency in the perception of fear and loneliness (Table 3). These results are in line with the analysis carried out by using the ANOVA model. For example, the factor score is on average 0.09 higher in children who often or always feel angry than in those who do not or rarely do ($p < 0.05$), while it is on average 0.14 lower in children who often or always feel alone than in those who do not ($p < 0.01$).

4. Discussion

The results of the bivariate analysis on cyberbullying revealed that both perpetration and victimisation are widespread among the respondents, involving, respectively, three and two out of ten children. However, this finding cannot be easily compared with official statistics, since, as we mentioned in the introduction paragraph, most of the quantitative studies assessing the prevalence rates of cyberbullying perpetration and victimisation have been carried out on middle and high school students. Furthermore, according to a recent review of studies with a representative population sample, due to the different measurement tools used, the prevalence of cyberbullying victimization and perpetration in the European Union ranged between 2.8 and 31.5% and between 3.0 and 30.6%, respectively [75]. Concerning online grooming, whose prevalence rate ranges between 9% and 19% [76], more than one out of ten children were involved in these episodes during the year prior to the survey without any significant difference between boys and girls. Indeed, if among adolescents the risk of involvement in this phenomenon is higher for girls [77,78], among children under the age of 13 this gender difference is less significant [50].

Regarding gender differences in cyberbullying involvement, the hypotheses were set due to the inconsistencies in the scientific literature about its influence on the phenomenon. As the results show, in cyberbullying perpetration, there are no relevant differences between girls and boys, while the prevalence rate of cyberbullying victimisation is higher among boys than among girls. In this regard, we hypothesise that boys were more likely to be victims since they were more exposed to the Internet, showing higher levels of screen time than girls, both on social media and applications and on videogames. In fact, looking at the results of the bivariate analysis, among hyperconnected children, the share of actors and victims of cyberbullying and of online grooming victims is considerably higher than among children with lower levels of screen time. This result is in line with the findings of several studies and our hypothesis (H2 and H3), which include the high level of technology exposure among the main risk factors for the involvement in cyberbullying and online grooming [7,8].

For this reason, we chose to use the screen time indicators, alongside the variables on cyberbullying and online grooming episodes, to carry out the factor analysis and detect the latent dimensions of these phenomena. The four factors obtained identify, respectively, four different dimensions, as follows: the dimension of hyperconnection and online grooming victimisation, the dimension of direct forms of cyberbullying (both suffered and perpetrated) and of online grooming victimisation, the dimension of indirect forms of cyberbullying (both suffered and perpetrated) and of online grooming victimisation, and the dimension of cyberbullying perpetration.

The analysis of the factor scores by subgroups shows that most of the hypotheses, which were formulated starting from the findings in the scientific literature, have been validated (H1, H2 and H3). Indeed, there are recurrent characteristics that are transversal to the four factors, suggesting that cyberbullying victimisation and perpetration and online grooming victimisation have common traits. Thus, higher scores were recorded among older children (H1) with low levels of parental education and low parental employment status, as well as among respondents with scarce parental supervision of their online activities. Furthermore, the risk of involvement increases among children with a higher tendency to adopt phubbing behaviours and to argue with friends, among respondents who do not enjoy attending school and who would feel discomfort with the impossibility of using digital devices for a week, and among children with low levels of prosociality (except for the fourth factor where children involved showed a high level of prosociality).

Moreover, as was hypothesised (H4), sport practice is not a predictor of children's involvement in these phenomena. This result confirms the findings of other studies that we have carried out in recent years, which shows that the idea that playing sport is always a protective factor for youth behaviours is a stereotype.

However, the hypothesis that a disadvantaged socio-economic context was a predictor for greater involvement in both cyberbullying and online grooming, which was part of the H2 and H3 hypotheses, has been falsified. In fact, the results show that the differences between the 8th and 6th districts, which are, respectively, an urban and a suburban area of Rome, are quite inconsistent. In this regard, there are some studies on the relationships between bullying and cyberbullying prevalence and the kind of geographical areas reporting higher rates of cyberbullying in urban areas and higher rates of bullying in suburban areas [79–82]. These different trends are usually attributed to the greater availability of digital devices and Internet access in urban areas. However, in our study, we did not find significant variations among children of the two districts in terms of screen time and availability of digital devices. To better understand these trends, further studies carried out on representative samples are needed.

Finally, as we hypothesised (H2 and H3), the emotional discomfort of children was also a predictor of involvement in these phenomena. Furthermore, the negative emotion perceived turned out to be the discriminating characteristic among the different dimensions identified with the factor analysis. In fact, the high frequency of anger was a common trait among all the factors; however, the dimension of cyberbullying perpetration, detected by the fourth factor, was characterised by low levels of loneliness and fear, in contrast with the other factors that identify simultaneously the dimensions of perpetration and victimisation. In this sense, it can be hypothesised that these children could have a leading role within their group of peers associated with aggressive behaviours that reinforce their need for control and domain.

5. Conclusions

The main contribution of the present study to the scientific literature is inherent to its quantitative and statistically representative nature—at a local level. Attitudes and behaviours of children are often analysed through qualitative tools and among small groups. Indeed, research using representative samples of this age group can give rise not only to high levels of complexity due to the young age of the respondents but also to the sensitivity of the topics of cyberbullying and online grooming, which is of utmost importance today. In our case, the methodologies and materials adopted, as well as the operationalisation phase, were crucial elements for the success of the study.

The complex research design involved an intense scouting activity with the primary schools, which was aimed at raising awareness about the importance of the research objectives. Although the research was carried out during the pandemic, facing strong restrictions to face-to-face contacts, the effectiveness of the scouting phase allowed the survey to be conducted within the classrooms and in the presence of two researchers, including the project coordinator, in order to guarantee the highest reliability of the collected data.

The need to measure and monitor the behaviour of primary school children through the quantitative method can no longer be postponed. The phenomenon of relational deviance concerns children more and more at a young age, and is amplified during growth. This is especially true looking at the problems that feed on the Internet, whose consumption, as demonstrated, increases with age. Furthermore, the physical distancing that occurred because of the spread of COVID-19 increased screen time, and therefore hyperconnection, intensifying the spread of the phenomena analysed by this study. The sudden growth in Internet use has also found both educators and families unprepared, especially in terms of knowledge of the control tools that can protect kids online.

The results of this study show a great prevalence of cyberbullying among children, especially among respondents with a high level of screen time. For this reason, it is important to monitor the trend towards social isolation and the use of cyberspace as the only means to interact with other people.

Furthermore, it is important to mention one of the distinctive elements of cyberbullying, which is the dual category of actor–victim. As the results of the factor analysis show, the dimensions of perpetration and victimisation often coexist in the same subjects, representing a further element of complexity in the recognition of the phenomenon by educators and parents.

Concerning online grooming victimisation, the relationship with the virtual world is highly dangerous, especially for children who do not have parental supervision on their online activities. In this case, the time spent in front of a screen, both on videogames and social media and applications, is the main predictor for the involvement of kids in online grooming.

These results confirm the need for further studies on this age group, and also for shared research tools and reliable indicators. This could be crucial to overcome the information gap on childhood behaviours, as well as to allow the standardisation of epistemological and methodological approaches. Only in this way will it be possible to clarify many of the current scientific controversies on the topics investigated and to produce reliable information based on representative samples. Although this study does not allow statistical inferences at a national level, due to the territoriality nature of the research on which it is based, the results are very helpful to deepen the knowledge of the phenomena's trends, encouraging new research with wider samples. In this regard, to validate the results of the present study and to find other predictive factors, it will be important to investigate the following dimensions: the tendency to social isolation and the increasing transposition of social interaction to the virtual world, the effects of the exposure to violent video games and multimedia contents, the frequency and intensity of negative primary emotions, and the influence of the social context on the youth behaviours. The outcome of this study, however, suggests that it is necessary to devote the utmost attention to the problem of cyberbullying and online grooming spread, reinforcing the cooperation among schools, parents and caregivers in encouraging children to use digital devices in a safer way.

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Notes

1 The city of Rome is divided into fifteen districts, which are called *municipi*. Each of these districts has different territorial extensions and population densities. The two selected areas represent, respectively, 9% and 5% of the resident population of Rome. The 6th and 8th districts are characterised by similar population densities (between 2000 and 3000 inhabitants per km^2) and heterogenous demographic and economic profiles. Together they have almost 400,000 inhabitants, which is equivalent to the population of a large city.

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Article

Chronological Progress of Blockchain in Science, Technology, Engineering and Math (STEM): A Systematic Analysis for Emerging Future Directions

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Abstract: The emergence of Industry 4.0 has awoken the adoption of blockchain as a key factor to enhance the industrial supply chain across the globe, enabling cost-effective and fast-paced delivery of products and services, ownership of products with privacy, and high security as well as traceability. This new digital horizon is underpinning the future direction of humankind, aligning with the Sustainable Development Goal themes of Good Health and Well-being (SDG3) and Sustainable Cities and Communities (SDG 11). Thus, the main objective of this paper is to elucidate the adoption of blockchain technology in Science, Technology, Engineering, and Math (STEM) disciplines by determining of the key academic research players and the evolution of blockchain in different fields. It begins by clarifying the definition of these concepts, followed by a discussion regarding the chronological progress of blockchain over time, an evaluation of the adoption of blockchain technologies in different key research areas, and lastly, providing comments on several directions to guide practitioners in developing a sustainable global blockchain roadmap in education science.

Keywords: STEM; blockchain; chronological analysis; science; technology

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1. Introduction

The Industry 4.0 era, a paradigm revolution from a mechanical technology emphasis era to a digital era, encompasses the interconnectivity of both Internet of Things (IoT) and smart manufacturing [1,2]. Notably, Industry 4.0 offers a more comprehensive, interlinked, and holistic approach to manufacturing in terms of massive capabilities of storage and computing via a cloud servers, effective process handling, and optimization via machine learning, and better visualization in decision making via digital twin's technology [3–5]. Beyond the innovation bottlenecks imposed by Industrial 1.0 to 3.0, Web 3.0 is envisioned as an open and decentralized version of the internet which enhances the shifting process of conventional industrial automation into the form of Digital Twins Cyber-Physical systems [6,7]. On this basis, Web 3.0 can be considered as a key aspect in the revolution of Industrial 4.0 under the prism of social, economic, and cultural of human mankind, including (a) social interaction between users in a virtual ecosystem [8,9]; (b) cryptocurrency as a certain domain of economic value [10]; and (c) allowing private ownership of self-production [11].

On the other hand, unsurprisingly, blockchain technology has become the center of focus for the realization of the new digital industrial 4.0 era due to its preferences for trustworthiness, decentralization, and also tamper-proofing, coordinating the theme between Industrial 4.0 and Web 3.0. Blockchain is a distributed ledger technology where an array of an individual blocks of transactions are stored anonymously in a decentralized ecosystem in which the users are in full control of their transactions, without the necessity of a trusted source or third-party authorities to verify the information [12]. In the last decade, blockchain has empowered and evolved to be a paradigm in the information technology perception, in which there are various broadly applied applications ranging from government to industries (i.e., crowdfunding [13,14], supply chain management [15,16], voting services [17], healthcare [18]. This is because blockchain technology has unwrapped ample knowledge gaps for the research community and provides a great deal of capacity in strengthening the cross-research development between different research areas [19,20]. With the combination of traits from a diverse range of areas such as cryptography, peer-to-peer networking, and decentralized ecosystem, research targeted on blockchain repeatedly surpasses the restrictions of the conventional research technique [21,22].

Furthermore, blockchain can be designated into a different form of network management, ranging from public to private sectors as well as the federal government [23,24]. Notably, integrity verification is one of the most important features of blockchain, which can save data anonymously and also link transactions for the creation of services (i.e., provenance and counterfeit, intellectual property (IP) management, and insurance). For instance, Ascribe (https://goascribe.com/, accessed on 5 February 2022) utilizes blockchain for linking digital content with creators, enabling a smooth transfer of ownership along with digital assets of loans without hassle in the process or high transfer service fees. Meanwhile, from a smart cities and societies perspective, blockchain can be a potential authority for exhilarating innovation by coupling Fog computing models with IoT blockchain [25]. One of the examples projected by Heidari and co-authors is that they reported that the digital taxonomy for the management of smart cities and societies could provide authority, privacy, and security to human life, enhancing the well-being of humans [26]. Besides aiding authority and privacy problem elimination, blockchain also enables the empowerment of new business models in the marketplace, which reduces the maintenance cost of data storing, enhances the security and privacy of ownership and improves the transaction's speed. Alas, the real-time adoption of blockchain is still in its infancy, specifically in science and engineering applications, lacking in-depth fundamental adoption that bridges academia, industry, and policymakers together.

The size and the composition of the Science, Technology, Engineering, and Math (STEM) workforce have gradually increased over the years, showing a positive trend in global demand, and experts have forecast that this number will continually rise at ~two- to three-fold in the next decades [27]. Recently, the government became aware that design-based learning principles, incorporating observation, prediction, communication, classification, and measurement skills, are essential skills for STEM disciplines [28]. Under this rule of thumb, the adoption of blockchain can be steep in a culture where "education" or "knowledge" or "information" sharing can be done easily and where everyone has a right to obtain it freely, without paying a high cost for access. One of the benefits is, blockchain would eliminate intermediaries' barriers between third parties, allowing for much more direct access to upskilling your knowledge and providing meaningful credit that leads to degree completion. For example, blockchain helps to capitalize on a number of STEM disciplines such as computing engineering and data science, which alleviate the shortage of workers in this niche area. Furthermore, blockchain could help in providing real-time STEM teaching where everyone can be placed in the same room, same thinking, and same ideology via metaverse technology, ensuring everyone is at the same pace of learning without being left out. On top of that, over the decades, there have been more advantages of the adoption of blockchain that have been reported in STEM fields, such as healthcare, data security management, finance, advanced manufacturing, and urban development, (see Figure 1).

Figure 1. Blockchain adoption in various STEM applications.

To the best of the authors' knowledge, this is the first study that sheds spotlight on the (a) emergence of blockchain technology and Web 3.0, (b) the blockchain platform operation in STEM disciplines, (c) the key academic players working along blockchain technology, and (d) the impacts of blockchain on humans and the environment. By doing so, we have evaluated numerous features, including benefits, challenges, and affordability of adoption of blockchain in each STEM discipline's technology. We have also taken into consideration the future work in great detail, highlighting all of the issues that need to be addressed. Some research questions are formulated to cater to the research gap:

Q1. What is the maturity level of blockchain applications in the STEM discipline?
Q2. How could blockchain fog computing, machine learning, IoT and, IoV aid in Web 3.0?
Q3. How many publications related to blockchain application in STEM disciplines can be found in the literature?
Q4. Who are the key players in blockchain applications?
Q5. What are the benefits of the adoption of blockchain technology in STEM applications?
Q6. What are the limitations or challenges that exist in the adoption phase of blockchain in STEM disciplines?

2. Methods

Motivated by the aforementioned observations, this study aims to provide an insight into the research activities and dynamics related to blockchain in terms of:

1. The revolution of web technology from the beginning of the late 19th century until today.
2. The "hotspot" of blockchain application and the key academic players in STEM via bibliometric analysis.
3. The chronological progress of blockchain in the disciplines of STEM, not limited to economic, finance, energy, and chemical research areas.

Over the years, bibliometric analysis has been acknowledged as one of the most preferred techniques for analyzing research trends, narrowing and understanding the network clustering—the relationship of the research theme. Most importantly, it can provide a big overview of the "hot topic" of the current research trend and the emerging state-of-art technology. The literature was retrieved for the last two decades (2000–2021) using the keyword search of "Blockchain" using the database of Scopus. Consequently, we utilize the maps generated by VOSviewer to carry out a comprehensive analysis of blockchain (https://www.vosviewer.com/, accessed on 5 February 2022).

To thoroughly cover the international research of "blockchain technology", we have utilized the Scopus@ database to acquire plentiful professional and scientific literature. Exported records from Scopus comprised complete and comprehensive information (cited references, full records exported to CSV files) on publication year, author, institution, and source journal. The search categories mostly focused on keywords, so that they discover correlation theories and research content in this context. In total, 46,164 valid documents were extracted from Scopus, with pre-analysis and comparison, keywords search for TITLE-ABS-KEY (blockchain AND technology); TITLE-ABS-KEY (blockchain AND engineering); TITLE-ABS-KEY (blockchain AND science); TITLE-ABS-KEY (blockchain AND mathematics); TITLE-ABS-KEY (blockchain AND mathematics); TITLE-ABS-KEY (blockchain AND business management); TITLE-ABS-KEY (blockchain AND energy); TITLE-ABS-KEY (blockchain AND engineering); TITLE-ABS-KEY (blockchain AND computer science); TITLE-ABS-KEY (blockchain AND environmental science); TITLE-ABS-KEY (blockchain AND decision science); TITLE-ABS-KEY (blockchain AND physics and astronomy); and the retrieval period was from 2016 to 2022, ensuring high reliability of the results.

3. Literature Review

The literature review is conducted to map the research systematically conducted in STEM disciplines and to identify any existing gaps in knowledge to which the scientific community can contribute.

3.1. Evaluation of the Evolutionary Progress of Web Technology

The spark of interest in Web technology can be backdated to the year 2004 (Web 2.0), when it capitulated the world from a static desktop web page to interactive experiences along with user-generated content (i.e., Airbnb, Friendster, and Facebook). This era was mainly driven by three fundamental layers, namely social, mobile, and cloud in limited and superficial conditions. Nonetheless, the Web 2.0 era is still fruitful, and currently, we are noticing the first glimpses of growth arising out of the next gigantic epitome shift in applications of the internet towards the Web 3.0 era.

Web 3.0 is a fresh new formation of architecture that fortifies the internet. The term was coined by Gavin Wood, and in the recent past has harvested substantial currency among specific futurists [29]. For a fair comparison purpose, Web 1.0 is represented through rudimentary read-only passivity in users, and those users browse a quite poorly organized framework at low bandwidths along with limited accessibility; meanwhile, Web 2.0 is represented through a dualist interaction between consumers and the producers of content. For instance, posting, blogging, and tweeting all portray active methods of content creation on these platforms. Accordingly, the Web 2.0 issue that was discussed by [30], stated that platforms on which all users interact are core pillars of power in their own right. The platforms such as Facebook (Meta) provide them with an astonishing degree of control over the structure of the internet. Correspondingly, in the streaming video category there are Netflix and YouTube; Twitter in microblogging; Amazon, eBay, and a few more for e-commerce; LinkedIn for professional networking; and lastly Google in the search engine segment. All of these will be curators of content and also ushers of useful information to the public. These oligopolies are denoted as the "Big Six" [31].

During the past few decades, the above-mentioned oligopolies have developed from, agile, low-profile outfits into powerhouses that govern their sub-areas, and also procured any firm that raised even the remotest challenge. Before adopting the Web 3.0 technology, the internet speed (5G) was bizarrely slower ($\times$10–100 times) than that of the internet speed in the year 2012 (4G) and 1999 (3G), respectively. Nonetheless, the question is to envision an improved architecture, and not remain hindered in the current scheme through discussing apprehension of stability to it; mainly since numerous people do recollect an age before the internet exist [10]. Overall, Web 3.0 is postulated on a "user-centric" architecture with a prominent characteristic of decentralized blockchain protocol [32]. Web3 is a group of protocols to offer core components for application creators. These components replace the old-fashioned web technologies such as AJAX, MySQL, and HTTP, and offer a new way of making applications. The user is provided with robust and verifiable assurances regarding the information they are receiving, the information they are giving, what they are paying, and In return what they are receiving. So basically, users act for themselves in low-barrier markets, and there is a guarantee of censorship along with monopolization that has rarer places to cover up.

3.2. Evaluation of the Chronological Progress of Blockchain

Figure 2 illustrates the timeline of the revolution of blockchain technology. The first emergence of digital cryptocurrency, known as Bitcoin, was invented by [33]. Several researchers have contributed substantial concern to blockchain technology. Nakamoto theorized the first-ever blockchain, where the technology has developed and established its way into several applications beyond cryptocurrencies.

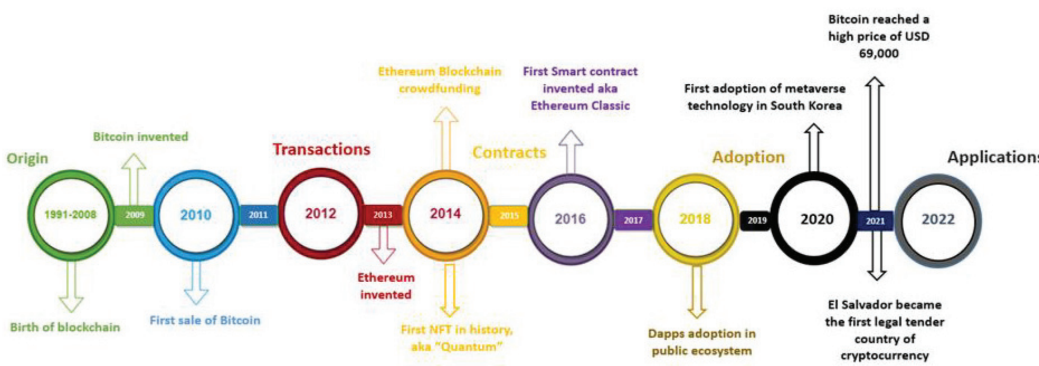

Figure 2. The revolution timeline of blockchain technology from 1991–2022.

Bitcoin sorts transactions and then clusters them into a controlled-sized structure known as blocks that share similar timestamps. The miners of the network (nodes) are accountable for connecting blocks in chronological order, and each block has the hash of an earlier block to help create a blockchain [34]. Consequently, the structure of blockchain achieves a robust registry of all transactions. Since Bitcoin, which is an application of blockchain, was introduced to the world, several applications have been gathered, all of them seeking to influence the capabilities of the digital ledger. As a result, blockchain history comprises a great number of applications that have developed with the evolution of the technology. The initial phase, which is considered the emergence of Bitcoin, is blockchain 1.0.

After that, concerned by Bitcoin's restrictions, Ethereum was introduced [35], which essentially delivers an infrastructure, similar to an operating system (OS), that can be built by everyone with their applications on top minus the necessity of high-priced enlargement of an own blockchain. Ethereum was invented as a novel public blockchain with additional perks related to Bitcoin, an expansion that ended up as a crucial period in blockchain history. Ethereum introduced a function called smart contracts (SCs) that are programmable in a certain type of languages, namely Java, GO, and Solidity [36]. This new feature of Ethereum provided a platform to create decentralized applications and progressed to become the largest application of Blockchain Terminal (A gateway that provides real-time validation, security and compliance for fund management) considering its aptitude to upkeep smart contracts utilized to execute numerous tasks. Furthermore, blockchain evolution does not rest solely on Ethereum and Bitcoin, but also other ecosystem such as Polkadot and Uniswap.

Amongst the most provocative things in cryptocurrency is how to resolve the transaction. There exist two leading types of consensus mechanisms, namely Proof of Work (PoW) and Proof of Stake (PoS). The PoW involves more electricity than PoS to PoW to authenticate nodes. PoS has a key issue in that it undergoes the likelihood of chain split, enabling process transactions quicker and at a lower cost than PoW, which is key for scalability (Cao et al., 2020). Recently, several other developments have cropped up to utilize the capabilities of blockchain technology, such as NEO cryptocurrency. It is a public smart contract cryptocurrency that portrays a PoS open-source that utilizes Delegated Byzantine Fault Tolerance (DBFT) technology; alternatively, it can support approximately 10,000 transactions per second. This consensus mechanism consumes the lowest electricity along with eradicating the chance of chain splitting [37].

In late 2019, Non-Fungible Token (NFT), a type of cryptocurrency that is driven by smart contracts of Ethereum has gathered astonishing attraction from both scientific and industrial communities [38]. The importance of NFTs cannot be overstated. NFTs are acknowledged as one of the futures of digital assets or technology that can be a reference standard for digital transactions. Unlike traditional currencies and tokens, NFTs are secure and decentralized. In other words, they cannot be controlled or stolen by any one entity. Also, NFTs are tamper-proof or immune to cyberattacks and cannot be altered or destroyed. This makes them a reliable way to store and exchange information.

Although NFTs have a marvelous influence on the present decentralized markets along with upcoming business prospects, the NFT technologies are however in quite a premature phase. Some possible challenges are mandatory to be sensibly embarked upon, whereas some favorable opportunities should be emphasized [39]. Furthermore, literature on NFTs, ranging from forum posts, codes, and blogs along with other foundations, are obtainable to the public. The first-ever NFT on Ethereum is CryptoPunks [40], whereas CryptoKitties (2021) place NFTs on notice with the gamification of the breeding mechanism. These participants fiercely contested at quite high prices for public sale the rare cats [41]. An imperative characteristic of NFTs is uniqueness, which makes NFTs appropriate for identity depiction, for instance, assets that are private and might be traded and transferred without restrictions.

NFTs are in a variety of interests these days, from play-to-earn gaming to self-collection. Lately, this technology has been adopted in STEM disciplines, such as Biotechnology, Education, and Engineering [42,43]. The first NFT in biotechnology is a breakthrough. It opens up a whole new world of possibilities for medical treatments and research. With this new technology, we can create customized treatments for patients with specific conditions. Additionally, we can use NFTs to create new models of disease and test potential treatments. This is a huge step forward for medicine and science. George Church and his co-founded company Nebula Genomics have advertised their plan to sell an NFT of Church's genome. Church is a geneticist at Harvard University in Cambridge, Massachusetts, who helped to launch the Human Genome Project, and is well known for controversial proposals, including resurrecting the woolly mammoth and creating a dating app based on DNA [38]. On the other hand, Jetking Infotrain Limited, a listed Indian computer networking organization, declares the launch of an assortment of 10,000 exceptional Web 3.0 Lion (NFTs) on the Ethereum blockchain. These NFTs will be accessible for exchanging enrolment and course expenses offered by the organization. In the metaverse, these sorts of virtual assets originated with certificates called NFTs that show ownership [44,45].

As a whole, blockchain technology is achieving new milestones day by day from cryptocurrency to NFTs, followed by the state-of-art metaverse. The metaverse is a virtual shared area that is open to everyone. It is a comprehensive term that states the entire digital as well as virtual world [46]. At present, numerous initiatives are emerging digital twins of the physical world we live in plus access to this digital world through the network. The metaverse is expected to address the issues of physical infrastructure in offering similar education. Instead of purchasing costly educational objects, they can be presented in the digital world for only one percent of the actual cost using virtual reality equipment. This state-of-the-art technology will lessen the difference between urban and rural students as well as providing the same level of education to everyone, no matter in which part of the world [47]. For instance, the rise of state-of-the-art "Metaverse-Digital Twins" technology is a life-changing frontier, where health care providers can interact within the augmented world globally and can immerse themselves in clinical discussion or perform a real-time virtual cardiovascular surgery that gives real experiences, which could increase the success rate of the intervention while minimizing the associated operative complications and risks [48]. The avatar-based 3D virtual ecosystem enables an easier collaboration among the academic researchers and the practitioner, connecting the science to real-world practical applications. Also, the Internet of Vehicles (IoV), another paradigm for advanced automotive networks. With the aids of 5G, data sharing and storage from the autonomous vehicles can be implemented in real time, meaning better road safety and lower traffic causalities. Through the decentralized blockchain ecosystem, secure and privacy-preserving services for the vehicles' network can be achieved via the device-to-device (D2D) communication technology [49].

4. Discussion

4.1. Bibliometric—Hotspot Analysis

The publication's annual tendency encourages discovering the development stage, knowledge accretion, and blockchain maturity. As illustrated in Figure 3, the total number of articles published in 2016 was merely 85. In 2017, articles associated with blockchain showed rather slow growth, just 463 articles, and 2018 was the start of massive growth in articles with 2206 articles. From 2019 onwards, the popularity of blockchain technology increased and 5858 articles were published, in 2020 reaching 10,509 articles. Further, 17,625 articles were published in 2021, which was the highest number of articles in a single year, and 9409 articles in 2022.

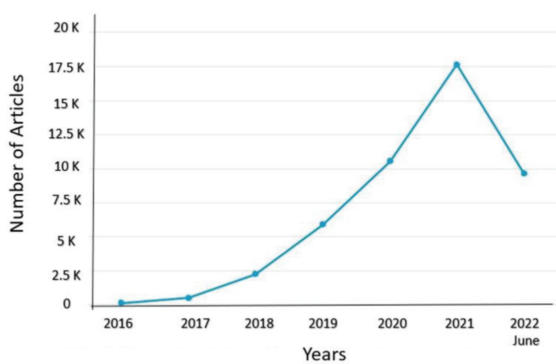

Figure 3. Publications per year based on keywords.

4.2. Subject Categorical Analysis

Blockchain literature in Scopus comprised several subject categories. The top 10 subject categories are illustrated in Figure 4, including computer science (31.2%) and engineering 21.4% as two of the hottest subject areas among other top subject areas based on keyword searches in the last decade. The number of publications in each group replicated the progress drifts of blockchain research in diverse areas. Generally, in the blockchain technology domain, a substantial proportion of current blockchain-related literature was mostly represented by cryptocurrencies (categorized under the field of finance). Nevertheless, based on our bibliometric analysis, the comparatively huge number of a diverse range of applications also highlights the interdisciplinary potential of blockchain technology. The subcategories below deliver a sound grouping of the existing blockchain-enabled STEM applications based on scrutiny of available literature.

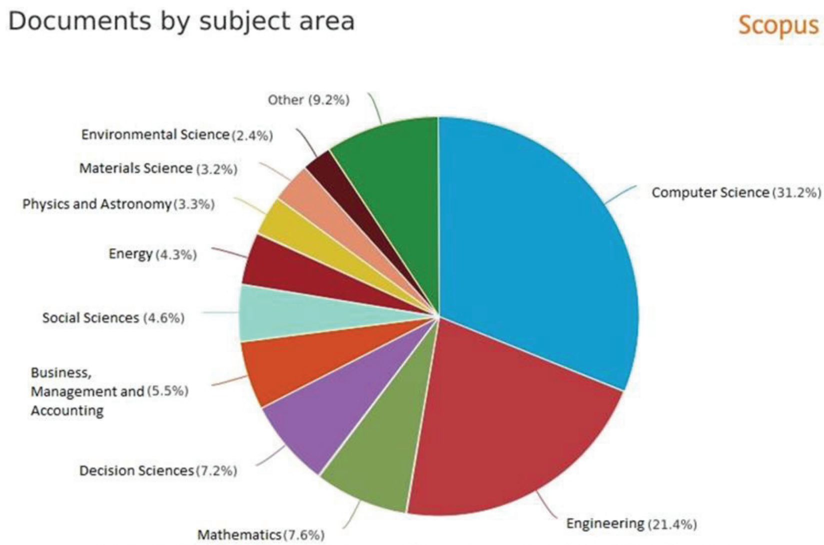

Figure 4. Subject categories analysis based on publications regarding the keywords.

4.2.1. Urban Development with IoT

Recently, IoT is expressively accelerating in the Information and Communication Technology (ICT) field [50–52]. IoT frameworks implement the centralized server-client model, assimilating things with cloud servers via the internet and therefore offering users several services [25]. IoT technologies along with blockchain are vast already through their expansion potential. Apart from that, these two fields are innumerably more entwined. For example, regardless of the downsides experienced by Wireless Sensor Networks (WSNs), which are a mainstay of scientific and human evolution [53], strong architectures of blockchains might be able to boost their IoT architecture by exploiting its ability while minimalizing insufficiencies [54]. Furthermore, growing consideration and investments for employing decentralized IoT systems are primarily impelled through blockchain technology and its intrinsic proficiencies [55].

Additionally, working in an automated and decentralized fashion empowers high scalability of the network along with effective management [56,57]. The interoperability nature of blockchain empowers independent and secure real-time payment services, amplifying traditional commerce and e-commerce along with public and private transportation systems [55,58,59]. Likewise, the employment of blockchain in ICT is highly mature; on this basis, the paradigm of blockchain technology in ICT can be expressed as "Urban Development for the creation of Future Smart Cities" [54,60]. For instance, Pazaitis and co-authors define an intellectual model of economics, which is blockchain-based decentralized cooperation, that may better aid the progress of social sharing between communities [61], such as infrastructure sharing and facilities sharing, and this will create never-before-seen efficiencies in city functions with a low environmental footprint. Sun et al. discuss the influence of developing blockchain technologies on three main aspects of the sharing economy (i.e., organization, technology, and human). They further examine in what way blockchain-based sharing services impart to smart cities [62], categorizing human perspective from the angle of a sharing service, underpinning the role of key infrastructure, human population, and education in urban development [63].

Henceforward, IoT and Smart Learning Environments are the core elements that need to be adopted in STEM education, especially Smart Urbanization Education, where the development of a digital ecosystem and deployment of IoT technologies can be centered, equipping everyone with high-quality education (eliminating poverty) and benefiting the social economy of the developing or rural countries (aligned with SDGs goal 1, 4, and 11).

4.2.2. Finance

On the other hand, blockchain technology is also widely employed in several financial-related fields, namely, business services, financial assets settlement, economic transactions along with market prediction. Blockchain is likely to represent a crucial part of the sustainable growth of the global economy, as a result, favoring all of the consumers around the globe alongside the existing banking system [63]. Blockchain technology provides a considerable revolution to capital markets along with an efficient method of performing derivatives transactions.

Furthermore, if we associate the traditional fiat currencies with cryptocurrencies, which have an indigent reserve of values with no government interference and therefore consist of reduced-price constancy and also offer a swift method of the cheap medium of exchange. However, the value of cryptocurrencies is still measured in fiat currency. Another potential area is Prediction Marketplace Systems (PMS). The PMS aids as oracles might influence cryptocurrencies and businesses. The peer-to-peer networking (P2P) implementations of blockchain-based PMS, a PoW category that permits a swifter transaction than Bitcoin, an open-source cryptocurrency featuring Scrypt Merged mining that permits the user(s) to trade shares before an event happens under the paradigm of the wisdom of the crowds [64].

Similarly, several other fields are financial-oriented, namely syndicated loans, contingent convertible bonds, commercial property, proxy voting, automated compliance, over-the-counter market, and asset rehypothecation [65]. Over the years, blockchain implementation in the financial area has ultimately aided in cost savings in fields, namely centralized operations, compliance, business operations, and central finance reporting. On this basis, blockchain perhaps is an important foundation for stimulating invention through automated, enhanced, and improved business processes [66]. There are several e-business models evolving and these models rely upon the IoT blockchain. For example, Zhang and Wen presented a smart contracts-based business model in which a blockchain distributed database is utilized to accomplish transactions amongst different devices [56]. Additionally, blockchain applications deliver commercialization prospects and substantial performance improvement, empowering IoT firms to revamp their operations along with strengthening integrity in the e-commerce domain. Simultaneously, the applications based on blockchain technology could benefit enterprises through implementing them as business process management systems. On such a basis, blockchain can play a vital role in maintaining each business process, and smart contracts may be engaged in executing the business routing, thus shrinking cost, coupled with streamlining intra-organizational procedures.

Furthermore, in the supply chain domain, blockchain technology plays the most crucial role and is most likely to provide an upsurge in accountability along with transparency. After primarily sourced merchandise is mass-produced and circulated to consumers, goods are determined as a supply chain. Therefore, supply chain managers conclusively intend to produce efficient goods for supply and ensure end-user satisfaction despite having to waver in the budget. By utilizing blockchain technology, logistic firms can have product tracking data and sustainability along with enhanced quality products possibly distributed within the entire supply chain network, which will help in enhancing time, risk management, and cost as well. Additionally, in the supply chain, the utilization of blockchain-based applications can preserve security, resulting in robust contract management systems between third- and fourth-party logistics [67]. With the help of a smart contract, payment can be processed automatically during the process of returning a product to the supplier or issuer. The payment can be automated with a smart contract when returning a product to the issuer or seller. The supply chain can have consensus-verified real-time tracking, connecting all members on the same platform.

As a whole, a step beyond the disruption and gaining the knowledge and skills to tackle financial services innovation via blockchain can be obtained in Fintech education. Within the Fintech education boundaries, students can experience the digital real-life challenges that reflect the dynamic nature of the current financial landscape and the transition from the traditional to the new digital era (aligned with SDGs 4, 8, and 12).

4.2.3. Healthcare Applications

Blockchain technology has progressed and is able to play a crucial role in the healthcare sector through numerous applications in fields, namely, longitudinal healthcare records, public healthcare management, user-oriented medical research, online patient access, patient medical data sharing, automated health claims settlement, clinical trial, drug counterfeiting, and precision medicine [68–70]. Particularly, blockchain technology along with the utilization of smart contracts could resolve issues of scientific reliability of finding things such as endpoint switching, data dredging, selective publication, and missing data in clinical trials.

One of the most promising adoptions of blockchain in healthcare is the integration of the blockchain with Electronic Healthcare Records (EHRs) of patients [71,72]. Basically, the patient's medical records, predictions, and data along with information relating to the condition of the patient and clinical development during the time of treatment are stored in EHR. So, by adopting such a technique, EHR based on a blockchain framework could be fruitful for patients to access and maintain the data that concomitantly promise privacy and security of the health records of the particular patient [73,74]. The EHR with of a blockchain-based system has multiple benefits: a distributed way of storing records that are public and also effortlessly verifiable over non-associated provider firms, no centralized holder or center for a hacker to breach the data or corrupt it, and data is updated and always obtainable while data from dissimilar sources is carried together in a single and amalgamated data repository [70].

In short, augmented reality and metaverse blockchain-related research are vital to be adopted in conventional healthcare management education as a sub-subject, i.e., digital health technology, augmented health infrastructure, 5G in healthcare. Healthcare practitioners do believe that the adoption of blockchain could upgrade the lifestyle of the patients, improve the healthcare quality and enhance the well-being of human mankind (aligned with SDGs 3, 4, and 17).

4.2.4. Advanced Manufacturing

The amalgamation of both virtual and physical structures in real-time data acquisition with blockchain-based digital twins (BBDTs) permitted live communications and permitted the operational effectiveness of unconventional manufacturing. In both biological and chemical preparations, the progress of bioassays frequently progresses in a composite and slow method to preserve high accuracy and precision [75]. As soon as they complete the authentication and optimization, the assay stays in use for a long period of time to decrease the most crucial factors, namely cost and waste. Consequently, in bulk production, the notion of lean manufacturing is quite fruitful to influence both capital expenditure and revenue [76]. For instance, BBDTs along with bioprocessing, together with multistage chemical production or else data acquisition and validation, biological cell cultivation, computational biomathematical optimization, and real-time data monitoring of bioreactors, perhaps steer to advanced operational efficiency along with a consistent product supply [77].

Furthermore, it provides participation of the inventor in tracking the traceability information of the supply chain of the dynamic manufacturing. This could provide a higher security than that of the traditional technologies because all parties must reach a consensus to place security blocks on top of encryption. It will reduce the chances of the data being stolen by another party [78]. Generally, the advanced manufacturing engineering education would not be limited to manufacturing itself but does cover a broad range of areas, including artificial intelligence, additive manufacturing digital systems, and control, creating a step closer to the Industrial 4.0 roadmap (aligned with SDG 9 and 12).

4.2.5. Data Storage and Security Management

Primarily, this is a real test when there is a huge amount of data to be stored, operated, and gathered, but lately, the dawn of data mining and machine learning methods have been established to overcome conventional data storage management [79,80]. The applications and implementations based on blockchain technology are not merely improved data storage and security management but also helped by default suitability because all of the operations are verifiable [81].

Numerous challenges regarding privacy, security, and also centralized trust even now affect the advancement of Big Data in IoT. To manage the decentralization of distributed data processing, blockchain was being implemented. Contrasting to other procedures, blockchain permits data security and resolves the privacy problems in the Big Data area [82]. With the aim to stress, the significance of trustiness in the Big Data Management Field presented a trustworthy Big Data blockchain-based sharing model, which achieved to guarantee the secure flow of data resources along with integrating a smart contract technology. Yang et al. utilized a keyword search facility and cryptographic primitives to help create a framework allowing secure and distributed client data management [83]. In addition, read and search authorizations of the data can be approved through their holder to third parties.

Moreover, in the instance of secure data distribution, utilization of a blockchain-based solution for metadata supportive key functions also confers its involvement towards both sustainability and management of digital archives. A blockchain-based system allows better security in the marketplace of data trading. To individually send protected, consistent data to centralized cloud systems, fog computers must be suitably situated in fog [25]. Nevertheless, noteworthy problems might impede the cloud system because of two main downsides such as shutdown and reprocessing of fog computers. Foremost security characteristics are emphasized through blockchain technology due to digital signature along with consensus amongst fog computers that permit sharing and monitoring the authentic transactions.

As a whole, blockchain plays a very important part in information and communication technology education, providing ways to tackle sustainable management issues related to data security and trusts, (i.e., planning and design, bidding, obtaining consensus in secret documents, and preventing malware attacks. The anonymous feature of blockchain also acknowledged as most cost-effective approach to achieve a sustainable growth of the IoV network's ecosystem by keeping vehicles' identities hidden while maintaining their privacy (digital automobile world) [84]. The futuristic features of this technology is highly required in many big ICT companies such as Meta, Amazon, and Google, providing a huge job opportunity (aligned with SDGs 2, 16, and 17).

4.2.6. Other STEM Applications

The progress in nanotechnology together with both technologies, namely computational and communications, has built a way for unproblematic integration of electronics and also flexible sensors, which is proved to be quite valuable growth, exclusively in the health industry, as already pointed out. The IoT coupled with nanotechnology has built a worthy prospect for plentiful applications to be industrialized in health monitoring systems, agriculture, and several other applications. The progress of nanomachines consents nanodevices to create, compute, transmit, and gather data at the nanoscale. The communication of the linked devices at the nanoscale coupled with current classical communication networks at high speed has directed the development of the internet of nano things (IoNT). The IoNT benefits several sectors are found in agriculture, health monitoring systems, oil and gas, and multimedia coupled with several other applications [85].

One of the biggest achievements of the application is combining nanotechnology and blockchain for COVID-19 immunity passports [85]. This could ensure the authenticity of the health data of each individual, allowing policymakers and health agencies to formulate new plans and safety measures to contain the spread of COVID-19 and other diseases in a short period of time. Also, the integration of blockchain can degrade the COVID-19 pandemic by a variety of methods, including patient monitoring, management, imaging methods, and medication [86,87]. On the other hand, from the perspective of nano energy, blockchain is likely to resolve issues, namely energy storage, fuel, power generation, and solar cells. This will establish a further business opening in the advancement of energy storage technologies and renewable energy, aligning with the theme of Industrial 4.0 [86]. For instance, the adoption of blockchain for decentralized and distributed energy markets could facilitate the market mechanism to deliver the energy system of the future without government subsidy.

In short, the adoption of "Blockchain Energy & Utilities" into renewable energy engineering education is somehow highly beneficial, preparing the students in higher education and equipping them with the knowledge before the energy revolution (the blooming of the distributed energy resources via solar and electric car). On the other hand, blockchain education should also be encompassed in other education sectors such as agriculture (Agritech 5.0 revolution), nanotechnology (NanoWorld revolution), and pharmaceutical (digital pharma) (aligned with SDGs 6, 7, and 13)

4.3. Countries and Institutions Analysis

By examining the geographic and spatial distribution of articles from each country, we could know where the "hotspot" of blockchain application in STEM disciplines is. Based on Figure 5, a significant difference in the number of publications among various countries can be seen: China has the largest output of academic papers, which is around 14,473 articles, followed by India with 7513 and the USA with 5200 articles, respectively. In the current context, the articles published in these three countries are accommodating more than 70% of the total publication in this field. The country collaboration system of blockchain research is illustrated in Figure 6, and the size of nodes signified a diverse range of articles published related to the keywords of blockchain on a global scale; the bigger the size of the nodes means more related articles were published in that respective country. It is worth specifying that high significance hinted at the standing of nodes.

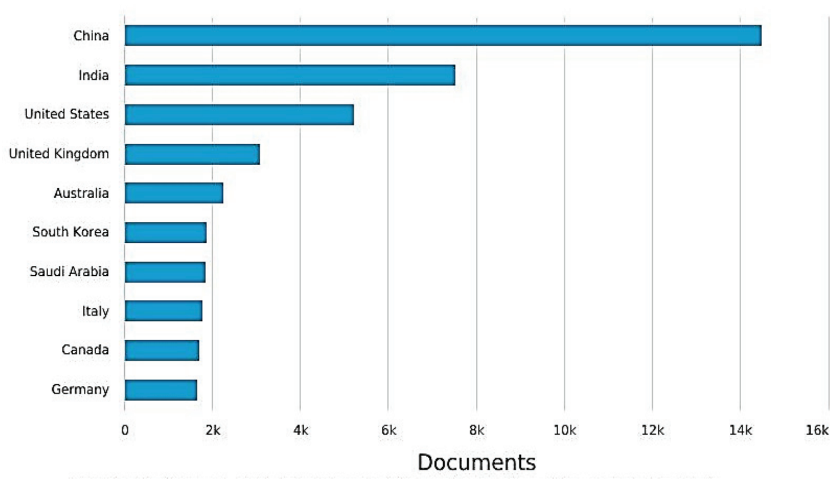

Figure 5. Number of STEM-blockchain-related articles published in various countries.

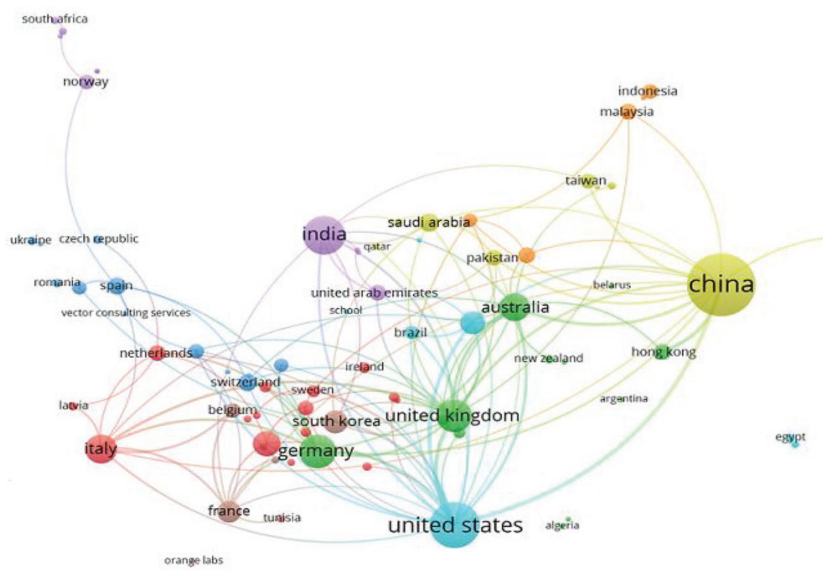

Figure 6. The visualization map of countries participating in blockchain research.

Figure 7 represents the top 10 institutions that contributed the most toward blockchain-STEM-related studies in the form of both collaborative and non-collaborative studies. Surprisingly, USA and Indian institutions are not listed in the top 10 ranking of the highest publication in Blockchain-STEM disciplines by the institution. The authors/researchers working in this field are concentrated in Asia, specifically in China, followed by Italy and Australia. Collectively, Peking University, Tsinghua University, and the UNSW have more active researchers in collaborative works, and the core research direction is found to be science and technology.

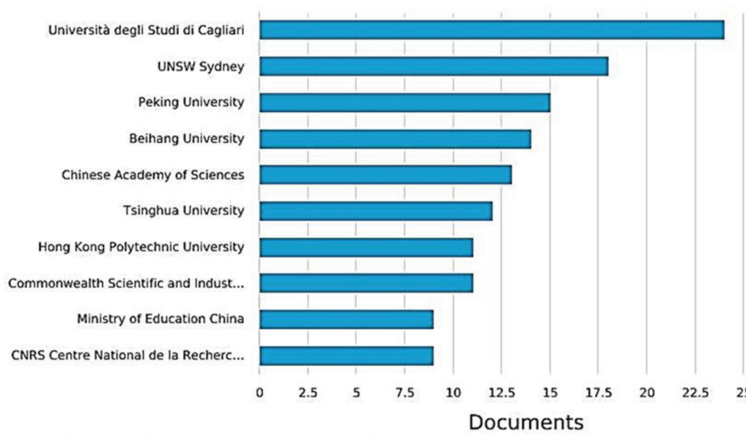

Figure 7. Top 10 institutions that published most STEM-blockchain-related work in literature.

5. Conclusions

In regard to implications for research on blockchain development, the growing number of publications on this topic indicates that there is a huge potential for blockchain that can be utilized in the field of STEM, shaping a sustainable digital future. Web 3.0, which includes Cloud, IoT, IoV, fog computing, and blockchain are the cutting-edge developments that have enormous growth in STEM disciplines, and the integration of all these technologies will have a great positive influence on human well-being, communities, and nations in particular. Significantly, under the domain of blockchain, numerous research projects have projected good results and thus far have proven that it is a value-added criterion for research design and planning, especially in the field of science and technology. To provide a thorough understanding of the implication of blockchain, future works are suggested as below:

(a) Integrated Economy, Environmental, and Energy (3Es) analyses should be carried out to evaluate the sustainable metric of blockchain adoption in various disciplines.
(b) Strength, Weakness, Opportunity, and Threat (SWOT) analysis should be carried out to evaluate the possible challenges and opportunities across the field.
(c) Policy-tree decision study should be carried out to provide a preliminary overview of blockchain, enabling the decisionmakers to analyze and plan the roadmap of Industrial 4.0.
(d) Integrating renewable energy with blockchain technology is a new breakthrough that should be looked into.
(e) Combining blockchain technology with engineering research will be highly beneficial in terms of optimization, cost-effectiveness, and time-saving, specifically in the field of nanotechnology and biology.

Some limitations that we encountered are also enlightened as follows: The bibliometric analysis is limited to the database of WOS and Scopus where non-English blockchain related-documents or non-indexed literature are not being taken into consideration. Another shortcoming of this work is the literature that utilizes partially blockchain technology in their work, which lacks detailed descriptions of their methods or approaches that are being neglected (due to low accessibility and maturity). Nevertheless, as a whole, the findings in this paper still can serve as a preliminary practical guideline for the future development of STEM disciplines, not solely on the research on system design and data management but also for the realization of Industrial 4.0. Lastly, all the research questions that were derived at the beginning of the work are successfully addressed as follows:

A1. The maturity level of blockchain applications in STEM is still in the infant stage, and still has room for improvement in the near future.
A2. The adaption of fog computing, machine learning, IoT, and IoV are found to be highly beneficial in Web 3.0, speeding up the global digitalization and industrial 4.0 realization.
A3. The publications related to blockchain application in STEM disciplines are in the range of 10,000–50,000 pieces.
A4. Most academia key players that work in this field are from Canada, Australia, and the USA.
A5. The adoption of blockchain technology in STEM applications could further aid a blueprint for "peace and prosperity for people and the planet", aligned with the SDGs.
A6. The main challenges in the adoption phase of blockchain in STEM disciplines are found to be scalability, regulations, and cost of implementation.

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sustainability

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Citizen Science in the Promotion of Sustainability: The Importance of Smart Education for Smart Societies

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Abstract: Digital society is already a reality and is increasingly shaping many aspects of social, economic and political life, among other aspects. The concept of Society 5.0 is a proposed form of a possible political nature to fulfil this digital society through a super-smart society. Based on document analysis of articles and books on this topic, this conceptual paper aims to critically discuss some aspects of Society 5.0, such as the dimensions of digitalization and sustainability. It is concluded that Society 5.0 is not an inevitability, and that the transformations it entails, as well as its advantages, also have challenges and limitations that should be considered, such as the risk of reproducing old forms of micro, meso and macrosocial inequalities within each country and between countries and regions, and, at the same time, creating new forms of social, cultural, economic and political inequalities, among others. A critical spirit seems to be necessary in the follow-up of this Society 5.0 and for which citizen-science logic, in an interdisciplinary way, can potentially provide tools for previous and prospective analysis of its implementation. We justify the need for smart education in these smart societies as a way of contributing to responding to the pressing problem of sustainability. It is smart education in and for a super smart society.

Keywords: society 5.0; digital society; smart education; super-smart society; sustainability; digitalization; citizen science

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1. Introduction

The digital society is already upon us and increasingly shapes numerous aspects of social, economic and political life, among other dimensions. In this context, the digital presence was amplified with the COVID-19 pandemic, which was caused by the severe acute respiratory syndrome coronavirus type 2 (SARS-CoV-2) [1–5], albeit with inequalities between countries and regions, and social, cultural and even gender inequalities [6,7]. The concept of Society 5.0 is a proposed form of a political nature possible to achieve this digital society through a super-smart society [8].

On sustainability, a centrally guiding framework is the 17 Sustainable Development Goals (SDGs) proposed by the United Nations [9,10], which refer to a multidimensional concept based on economic and social growth that respects the environment. According to this concept, economic development fosters actions that are financially sustainable, and the use of natural resources is efficient, thus adding to the decrease in the environmental impacts of the manufacturing industry [11].

Education for sustainability is pivotal to meeting these Sustainable Development Goals [12] inasmuch as these sustainable development trends underlie UNESCO's four education principles [11] (p. 579):

- Education as a fundamental human right;

- Education as a public good;
- Education as a foundation for human fulfilment, peace, sustainable development, economic growth, decent work, gender equality and responsible global citizenship;
- Education as a contributor to reducing inequality and poverty.

However, Education for Sustainable Development (ESD) places some relevant challenges to traditional curricula and formal education, insofar as it calls for systemic and critical thinking and interdisciplinarity. Indeed, and according to Zeeshan et al. [10] (p. 1), "Conventional educational settings remain the Achilles heel of sustainable education".

This conceptual paper aims to critically discuss some aspects of Society 5.0, such as the dimensions of digitalization and sustainability. It is also intended to discuss the importance, in an interdisciplinary way, of applying the logic of citizen science to the understanding and overcoming of these challenges.

2. Materials and Methods

The methodological approach chosen for the production of this paper is qualitative, and the research technique used in the analysis of the data collected was content analysis. This technique allows compression of a high amount of words and text into fewer content categories based on explicit rules of coding [13–15]. Bardin [13] advocates that content analysis incorporates a set of communication analysis techniques that use systematic and objective procedures to describe the content of messages conveyed through diverse communication outlets. Thus, when used correctly, content analysis is a powerful technique that allows researchers to filter large volumes of data more easily and systematically [14,16]. It is a useful technique that makes it possible to unveil and describe the focus of individual, group, institutional or social attention, with the advantage of being discreet and useful when dealing with high volumes of data [17].

A critical decision when choosing content analysis is the selection of the unit of analysis. The literature refers to the unit of analysis regarding a wide range of objects of study, namely an individual, a program, an institution or a community, an interview, part of a text or even a sentence [18]. Within the scope of this study, we chose the document as the unit of analysis.

The authors performed a literature search, using, as search terms, Society 5.0, digital society, higher education, soft skills, digital, universities, and super-smart society mentioned either in the title or in the abstract. The search took place between 21 and 28 February 2022, and the databases searched were B-ON [19] and SCILIT [20]. This literature search resulted in 74 publications, described in Table 1.

Table 1. Document sources analyzed and their characterization.

Type of Document		Geographical Scope		Year of Publication			
Theoretical/ Conceptual	**Empirical**	**International**	**National**	**2022**	**2021**	**2020**	**Prior to 2020**
49	25	52	22	5	40	15	14
Total: 74 publications							

Source: Authors' production.

As mentioned, the collected data were treated and analyzed through the content analysis technique [13] so as to meet the objectives drawn for this research in a comprehensive, rigorous and grounded way. According to the methodological approach adopted, a set of categories was built and coded a priori based on a critical review of the literature on the topic under analysis (citizen science, promotion of sustainability, smart education and smart societies). However, the categorization initially created was not a closed system; data analysis allowed the establishment of emerging categories, i.e., categories that were, based on their relevance to the study, incorporated into the categorical system as the data analysis progressed. Thus, the following categories emerged from the analysis of the documents:

Society 5.0; digitainability; digitalization and sustainability; Society 5.0 and citizen science; and smart education. Each of the categories is analyzed in detail in the sections that follow.

3. Society 5.0

We live in an increasingly digital society, with many challenges emerging from this [1,21,22].

Society 5.0 embodies the transformations brought about by this digital society. It is a recent concept with an essentially political origin. This concept emerged in Japan as a super-smart society, and its purpose, articulating the virtual with the real world, is human and social development in fostering quality of life and economic growth with cohesion and social justice while respecting sustainability [1,8,21–29].

Society 5.0 is the most recent stage of human development. Before it, very briefly, Society 1.0 was characterized by groups of humans who hunted to survive and lived in a totally balanced way with nature; Society 2.0 began when groups started to develop agriculture, social organization and the formation of nations; Society 3.0 corresponds to the Industrial Revolution, with the emergence of industrialization and mass production; Society 4.0 introduced the concept of an information society through global connection and worldwide information networks. It led to a digital transformation of the information society, allowing the emergence of Society 5.0, which is, thus, the continuation and corollary of Society 4.0, but characterized by being human-centered. The big difference between these two societies is that, while Society 4.0 focuses on the reduction of costs and effective production techniques in industry, Society 5.0 focuses on society as a whole and is a human-centered society [28,30,31].

The world we live in is in permanent change, and the technological development we have been witnessing over the last decades is fast, constant and with profound influences on the lives of citizens. In this dynamic scenario, Society 5.0 has, as one of its main purposes, to place the individual as the epicenter of the choices that are made at various levels (e.g., social-, cultural- or economic-level decisions, among several others). Thus, the increase of social sustainability must take into account the establishment and development of a more inclusive society, in which digitalization should be put at the service of humanity [32] with a logic according to which no individual is left behind [21].

The core concept of the Society 5.0 model is the large-scale collection and garnering of real-time data from all sectors of society, and its fundamental purpose is to make the most of the technological transformation for the benefit of all its citizens, namely in problem-solving processes [21]. In this way, and according to this model, the individual is placed at the center of the various choices, from social to economic and cultural. Consequently, this model of society aims to build a more inclusive society in which digitalization is placed at the service of the individual to achieve so-called social sustainability. In this sense, technological innovation can and should be used to improve the functioning of societies in their various fields [32].

Having originated, as already mentioned, in Japan, Society 5.0 has been expanding on a planetary scale in the building of digital societies [24,26], having at its base a rather interesting paradox, which involves the establishment of a society in which the epicenter is the human being, implying their interaction with the most-diverse forms of artificial intelligence at the service of human beings, namely social robots and entities equipped with artificial intelligence, which are no longer passive agents that only execute the instructions they receive from humans but, rather, entities with learning, decision-making and autonomy abilities [23].

This Society 5.0, as a “system of systems” of interconnected elements linked to each other, with the mobilization of information and big data, and to and from the Internet in a digital way [25], has five principles to include all individuals, presented in Table 2.

Table 2. Society 5.0 principles.

Inclusivity
Sustainability
Human-centered approach
Innovative thinking
Improved governance

Source: Adapted from Mavrodieva and Shaw [33] (p. 11).

To achieve the intended goals and to ensure that this type of society is not controlled by large companies, it is critical to foster the effective participation of all [23,25,33]. This raises deeply complex challenges, not only in technical terms—of digitization—but also in terms of use by ordinary citizens [23,34], which implies "digitability", which the next section addresses.

4. Digitainability

Following Colás-Bravo, Conde-Jiménez and Reyes-de-Cózar [35], sustainability regards those actions that aim at enhancing contemporary societies' well-being in economic, social and educational terms while safeguarding future generations' living standards. Table 3 depicts the four sustainability areas that educational sustainability should cover.

Table 3. Sustainability areas of educational sustainability.

Environmental sustainability	Preservation of ecosystems and their conservation for future generations.
Economic sustainability	Promotion of economic growth that generates equitable wealth for all without damaging the environment.
Social sustainability	Assurance of social well-being; inclusion and equity; inequality reduction; inclusive education; gender equity; education and literacy for all; active and accountable citizenship; fostering of peace, justice, respect, diversity, social and cultural inclusion.
Educational sustainability	The articulation between gender equity, inclusion and lifelong learning in education.

Source: Based on Colás-Bravo et al. [35].

The 2030 17 SDGs (Figure 1) seek to achieve the development sustainability process by articulating human/social, economic and environmental development [36,37], respecting the past, present and future in harmony between society and nature [12].

Digitalization and digital transformation are pivotal for the 2030 Agenda goals to be attained and, thus, also for the accomplishment of most SDGs [3].

Digital transformation may be defined, according to Jummai [38], as all the changes that take place at all levels of any organization—regardless of its type—in terms of its culture and ways of functioning, through the adoption of digital technologies, processes and competences that foster the organization's development and enhancement.

The Internet plays a pivotal role in these changes, not only at the organizational level but also in terms of individuals' daily life. It allows people to interact with each other, to be permanently connected with the world, to know what is happening at the global level in real-time—in sum, to be socially linked to everything and everyone that surrounds them [11].

Figure 1. UN Sustainable Development Goals. Source: Zeeshan et al. [10] (p. 6).

However, even with all the technological advances the world has experience over the last decades, there are still distinct levels of digital access and use, which the International Communications Union calls (i) the digital access gap, regarding those who are able to and those who are not able to utilize ICT (Information and Communication Technologies); (ii) the digital gap of use, which regards the competences and abilities to use ICT; and (iii) the quality-of-use gap, concerning the different ways in which different people use ICT [39].

Regarding the last dimension (the quality-of-use gap), it has to do with digital literacy, defined as

> [. . .] the individual's ability to identify in a digital environment and encompass basic knowledge, skills, and abilities related to digital hygiene, digital ethics, communication, technical and consumer security, the Internet of Things, XR, basics of data processing and analysis, as well as basic computer and Internet skills in the modern digital environment. [36] (p. 4)

In addition, the ability of individuals to show that they master the digital—that is, that they have digital literacy, both as consumers and as producers of digital artefacts—is critical for sustainable development [40]. This focus on the digital has produced a new term, "digitainability", which brings together "digitization" and "sustainability" and reflects the links between sustainability and digitalization [3].

Education is one of the most relevant arenas for digitalization, and it depends on digital processes for its advancement. One of these advancements is digital doubles, which consist of a digital model of an object (e.g., a part of the educational process) that "[. . .] repeats what is implemented by its existing prototype and also allows one to study the functioning of the latter" [12] (p. 6). Education has already started to and will experience major shifts as early as this century, namely in terms of the traditional teaching and learning processes and methods. Computerization, digitalization and the transition to sustainable development (SD) are at the heart of these shifts, the main purpose of which is to ensure that the way in which the contemporary generation is developed does not hamper the wellbeing of future generations [12]. The training of digital competences within the sustainability paradigm entails four fundamental dimensions: (i) the contextualization of knowledge, which regards the teaching of critical thinking skills that allow students to learn to reflect on the social, cultural and disciplinary conditions in which knowledge is produced; (ii) the sustainable use of technological resources, which implies the use of technologies in an eco-responsible way; (iii) collaborative processes that favor digital sustainability; and (iv) the respect for ethical principles [41,42] (Figure 2).

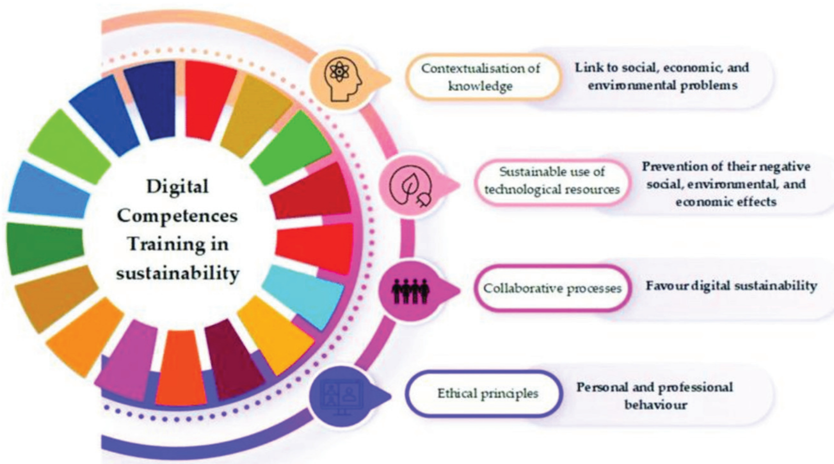

Figure 2. Areas of training in digital competences in sustainability. Source: Urrea-Solano et al. [41].

Thus, one of the main purposes and goals of sustainable digital education is to prepare today's individuals to commit themselves to be part of a responsible and sustainable social transformation and, in this way, to pave the way of sustainability for future generations [3,43,44].

These concerns underlying sustainable digital education are, naturally, in line with SGDs and, particularly, SDG#4 (quality education) [3], which occurs both inside and outside the educational system [35].

5. Digitalization and Sustainability

Currently, sustainability, in its multiple dimensions—social, economic and ecological, among others—is paramount. We are also living in unsustainability, having exceeded the limits of reasonability to have a successful future [45,46], with digitalization having the potential to create new consumption patterns [21].

This digitalization and the presence of the Internet entail profound changes in society. The developments brought about by digital transformation involve changes in terms of the quality of technologies, but also—and as a consequence—important changes at the level of social configurations. According to Meshcheryakova and Rogotneva [47] (p. 175), these changes and their direction are defined by four innovative technologies: "cloud computing, big data, artificial intelligence and the Internet of Things".

Digital literacy, as "access, consumption and production of digital forms" [1] (p. 4), in an intentional way is critical in this process of reducing the digital divide due to several cultural, economic and social factors of this (new) reality that shapes Society 5.0, as it is pivotal for the critical and conscious participation of the actors in the promotion of sustainable development [1].

As a way to ensure the attainment of a set of social priorities on a global scale, the United Nations (UN) approved, through its 2030 Agenda, a set of 17 Sustainable Development Goals (SDGs), whose fundamental goals are to protect the planet, eradicate poverty and to ensure the well-being of populations [48]. Table 4 presents the 17 SDGs defined by the UN.

Achieving these SDGs—which have been adopted by 193 countries, came into force in January 2016 and aim to stimulate economic growth, ensure social inclusion and protect the environment—means achieving the outcomes shown in Figure 3.

Albeit the implementation of this Society 5.0 model brings a wide range of advantages, it also has several drawbacks, which Table 5 accounts for.

Table 4. The 17 Sustainable Development Goals.

No poverty (SDG1)	Goal: Remove extreme poverty.
Zero hunger (SDG2)	Goal: Guarantee that all people have access to safe, nutritious and adequate food.
Good health and well-being (SDG3)	Goal: Supply people with basic health needs.
Quality education (SDG4)	Goal: Encourage equal, life-long and accessible education for all.
Gender equality (SDG5)	Goal: Provide gender equality in communities.
Clean water and sanitation (SDG6)	Goal: Take new measures so as to supply people with fresh and drinkable water.
Affordable and clean energy (SDG7)	Goal: Support energy production from resources that do not cause an increase in CO_2 emissions.
Decent work and economic growth (SDG8)	Goal: Ensure economic development and employing people in decent work.
Industry, innovation and infrastructure (SDG9)	Goal: Increase human welfare by creating innovations; and produce eligible products in accordance with human needs.
Reduced inequalities (SDG10)	Goal: Reduce inequalities among countries and within countries.
Sustainable cities and communities (SDG 11)	Goal: Reduce the life in slums; increase transportation facilities; arrange sewage and other infrastructure affecting human health; and plan decent sustainable cities.
Responsible consumption and production (SDG12)	Goal: Use food, water, houseware, electronic devices, energy and all fossil fuels economically and cyclically; and respect the future.
Climate action (SDG13)	Goal: Reduce the use of fossil fuels and the consumption of fossil-fuel dependent energy; take measures against natural disasters resulting from climate change; and develop counter measures.
Life under water (SDG14)	Goal: Ensure effective use of oceans, seas and those resources; create a healthy structure; and use resources sustainably.
Life on land (SDG15)	Goal: Protect ecosystems and species on earth and their sustainable use.
Peace, justice, and strong institutions (SDG16)	Goal: Form a more judicious and peaceful environment.
Partnerships for the goals (SDG17)	Goal: Help develop the whole world by enabling effective cooperation and communication among countries.

Source: Adapted from Zengin et al. [28] (pp. 5 and 6).

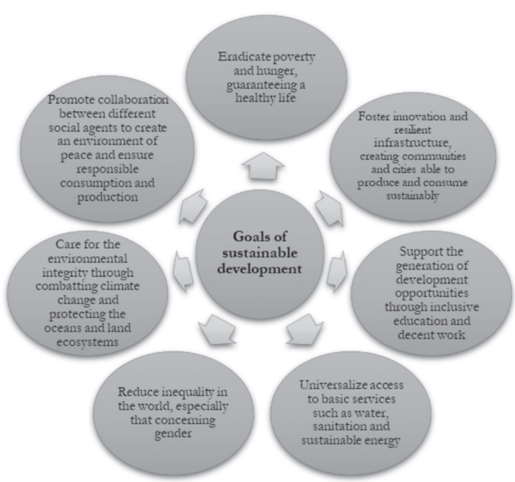

Figure 3. Goals of sustainable development. Source: Adapted from Mensah [48] (p. 11).

Table 5. Some disadvantages of implementing Society 5.0.

1	Society 5.0 implementation is the technological leap from 4G to 5G. This process is complex and requires significant improvements to avoid computer scientist attacks.
2	The digital evolution proposed in Society 5.0 is closely linked with IoT technologies; there is an exponential increase in the volume of important data of companies and human beings that can be affected by hackers.
3	Cobot (collaborative robot) implementation in industrial processes leads to a decrease in the number of workers and an increase in the salaries of specialized staff.
4	Technology must be changed and hardware becomes obsolete, generating environmental pollution over time.

Source: Adapted from Narvaez Rojas et al. [25] (p. 12).

Even with the existence of some disadvantages, the implementation of the Society 5.0 model is envisaged as an important step towards improving people's living conditions and achieving sustainable development.

Hence, alongside all the advantages of developing Society 5.0 also come shortcomings, and this concept has raised serious reservations about the democracy upon which it is supposed to be based by some of its critics. McMillan Cottom [49] (p. 443), for example, states that

> [...] To both expand and exclude, the platform-mediated era of capitalism that grew from Internet technologies specializes in predatory inclusion [which regards] including marginalized consumer-citizens into ostensibly democratizing mobility schemes on extractive terms.

McLaren [24] (pp. 567, 582 and 595) also offers a very pertinent critical position on Society 5.0 and casts doubt on the true intentions and consequences for individuals and societies of implementing the Society 5.0 model, arguing that

> While Society 5.0 seeks its solutions through further abstracting humanity from the natural world it is destroying, locking us in a deterministic bubble, Ecological Civilization seeks to re-embed us in nature, repair our dysfunctional relationships with it and promote freedom through transcendence to higher levels of development. [...] Society 5.0 is a surveillance society, one with a scale of projected electronic monitoring of human behaviour never before seen in our history. [...] Society 5.0, therefore, like surveillance capitalism more generally, is designed to stunt human development creating a population of compliant, comfortable idiots.

In turn, Žižek, Mulej and Potočnik [50] (p. 11) speak of Society 6.0, proposing a "Sustainable Socially Responsible Society 6.0", while upgrading Society 5.0 by the application of a Sustainable Socially Responsible Society 6.0 model, materializing a "Well-being Society 6.0". Figure 4 graphically presents what Žižek et al. [50] consider to be the 10 basic dimensions of well-being in a welfare society.

The overall well-being of citizens thus involves synergy—in the sense of a collective and simultaneous effort—between the various types of well-being: material, social and environmental [50]. The authors argue that this Society 6.0 must obey a set of postulates that should be put into practice by all organizations, whatever their type (Table 6).

Table 6. Basic postulates of modern humanity.

The responsibility of everyone for the influences on society, i.e., people and nature.
Interdependence between individuals.
Integrity/holism and interdisciplinary cooperation.

Source: Adapted from Žižek et al. [50] (pp. 15 and 16).

Figure 4. Dimensions of well-being in a "well-being" society. Source: Adapted from Žižek et al. [50] (p. 11).

The authors put forth what they call the output of Well-being Society 6.0, which encompasses three core dimensions: (1) Sustainable social responsibility, in personal, corporate and societal terms; (2) SSR behavior, requiring personally accountable citizens; and (3) Sustainable leadership leaders [50] (p. 16).

Moreover, building a sustainable global society and finding solutions to its crises and challenges requires, more than resorting to technological solutions, changing and correcting individual behaviors, defining public policies that shape the sustainable society, and a combined, global effort to address the complexity inherent in the social relationships and structures that shape history [51].

6. Society 5.0 and Citizen Science

For Society 5.0 to become a reality on a global scale, it is critical that societies promote social dialogue, explore technologies and foster the participation of all at all levels. Society 5.0 has as one of its central assumptions, as already mentioned, the active participation of all in social issues, i.e., it must ensure that all citizens have access to the same opportunities in the logic of full participation mediated by innovative technologies. This is the basis for sustainable development [29].

To fulfill this purpose, citizen science (CS) seems to be entirely relevant. However, this is a concept with several blurred meanings [52,53]. According to Skarzauskiene and Mačiulienė [54], citizen science has a deep connection with transdisciplinary research. This stance towards research entails, on the one hand, various fields of knowledge working together and, on the other hand, close cooperation in addressing, analyzing and searching for solutions to scientific and social problems. Citizen science is, therefore, pivotal in building more sustainable and inclusive societies with the aim of developing solutions for social issues.

In this sense, CS contributes to making scientific results clear to all, building citizens' trust in science and increasing collective awareness of socio–political problems, thus forming the basis for change [54].

According to Göbel et al. [53], there are several stakeholders involved and contributing to this CS fostering process, as presented in Figure 5.

Figure 5. Groups of stakeholders involved in the Citizen-Science process. Source: Adapted from Göbel et al. [53] (p. 335).

Well-being Society 6.0 promotes the interrelationships between all social actors as a way to prepare them for the social and economic consequences of the digitalization of societies.

The participation and active involvement of all stakeholders in digital CS involves the assumption of several roles, namely those of data provider, collaborator, co-creator, ideator and disruptor [55], in the exercise of citizenship. Table 7 details the meaning and scope of each of these roles.

Table 7. Some disadvantages of implementing Society 5.0.

Data provider	Collecting data on predefined issues
Collaborator	Collaborating with authorities to monitor issues predefined by authorities
Co-creator	Co-creating solutions to address issues of shared concern
Ideator	Ideating civic actions
Disruptor	Disrupting established processes by passive non-participation or negative participation

Source: Adapted from Palacin et al. [55] (p. 2).

Based on these participatory dynamics and the assumption that CS development inevitably involves the input of all citizens, Fan and Chen [52] categorize CS uses into four modes or types, which are not static or mutually exclusive, although they have significant differences between them (Figure 6).

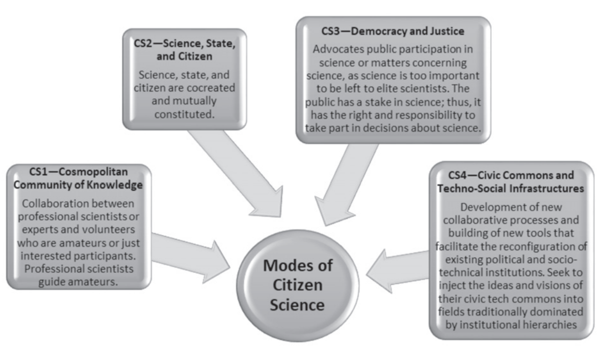

Figure 6. Modes of Citizen Science. Source: Adapted from Fan and Chen [52] (pp. 183–190).

CS turns scientific research into a participatory and shared process by involving citizens in its different stages. These dynamics of participation thus add to the democratization of science itself by actively inviting the contributions of nonprofessional scientists, but without abdicating the scientific rules and structures. Following Wagenknecht et al. [56] (p. 3), "The integration of diverse actors, knowledge bases and objectives in citizen science makes it necessary for its research processes to be open, transparent and comprehensible for all".

McMillan Cottom [49] calls this involvement of citizens in the processes of science production predatory inclusion, meaning it is the involvement of marginalized individuals in democratizing mobility processes, such as ethnic minority citizens, for example.

CS, as a "co-design process", entails flexibility, engagement, reflexivity, collaboration, participation, motivation of the various actors, time control, negotiation, relevance, permanent dialogue, inclusiveness, transparency, articulation of diverse perspectives and interests, heterogeneity, selection of stakeholders, the abolition of traditional hierarchical structures and, thus, functioning as a legitimizing factor in the research process and product [56,57].

For this participatory process to be successful and truly inclusive of all, a balance between the interests, goals and constraints of researchers and those of a heterogeneous group of stakeholders and citizens in general needs to be found. Indeed, "This diversity is essential to ensure legitimacy, relevance, transparency, and credibility, yet it introduces greater complexity to the practicalities of the process" [57] (p. 8).

CS has numerous advantages and benefits, both for science itself (by answering research questions, increasing knowledge, management and awareness, and introducing new epistemologies), for citizens (by increasing their awareness, knowledge and skills) and for policymakers (as it can influence policy and management actions). Table 8 presents the main advantages.

Table 8. Example of values of Citizen Science.

Provides raw data
Expands total knowledge
Validates models and data
Answers research questions
Increases project scope and intensity
Economic incentives
Introduces new methodologies and philosophies
Increases stewardships and awareness
Influences conservation actions
Increases knowledge and skills
Increases advocacy efforts
Influences policy and management
Connects people, governments and the environment

Source: Adapted from MacPhail and Colla [58] (p. 3).

While CS has important advantages and benefits, it also faces numerous challenges and difficulties, particularly in terms of participants' and researchers' issues, defining the research design, and collecting and using the data collected [58]. Figure 7 details some of these challenges.

Figure 7. Examples of challenges of Citizen Science. Source: Adapted from MacPhail and Colla [58] (p. 7).

Digitality is a factor that can enhance the CS process [57]. However, critical literacy [59], digital literacy [60] and sustainability literacy [54] are crucial for its success [56] inasmuch as they promote sustainability through a necessarily interdisciplinary science literacy. This is not inevitable and, at the same time, raises profound challenges—some of which are discussed in this conceptual paper—such as going against established ideas about what and how education should be carried out on the part of many stakeholders (educational policymakers and educational actors), as well as overcoming digital divides, and the nonreproduction of preexisting inequalities and the establishment of new inequalities, in an ever-dynamic process.

7. Smart Education

For education for sustainable development (ESD) to fulfil its purpose of enabling individuals to attain the knowledge, skills, attitudes and values to shape a sustainable future, it must go beyond the traditional education offered in the 20th century. New educational approaches require students to develop competences that were not present or valued in the curricula of traditional education in the last century and that promote digitainability, seen as citizens' ability to use digital technologies, both in their roles as consumers and as producers of goods and/or services. Among these competences are communication, critical thinking, problem-solving, creativity and innovation, just to name a few [61]. However, student development in these competences also requires preparing both teachers and students for a rapidly evolving world and new challenges, and aligns formal with informal education [62].

Indeed, individuals are constantly subject to informal education and learning [12], and new (digital) technologies mediate all this learning more than ever before, with individuals actively participating in and building their learning and knowledge in the logic of co-creation and communities of practice [11]. This scenario brings yet another challenge, with the increasing availability of new media calling for the need for individuals to develop their digital literacy (i.e., the ability to continually search and critically assess information and to interact with others in a virtual environment), which is now central in the learning process that takes place more and more outside the walls of the traditional classroom [4,62]. This new educational landscape is taking place right at the preschool education level [63], in what Prensky [64] calls the afterschool space. Thus, it is paramount that educational policymakers and educational actors at large understand how learning takes place outside of the school, namely through online tools, so that fundamental ESD values and competences, such as "[. . .] ethical online communities and the development of respectful, tolerant global digital citizens” [62] (p. 23) can take place [65].

In this new and fast-changing educational and social environment, educational processes that foster EDS need to use new educational instruments and pedagogical practices that enable students to attain core soft competences such as being able to cope with uncertainty and to adapt, be creative, communicate effectively, respect others and their standpoints, be self-confident, have emotional intelligence, be accountable and know how to think systemically [66], which is not always an easy or straightforward process.

One such tool is the DigCompEdu (European Framework for the Digital Competence of Educators) model, which specifies how digital competences should manifest in educational contexts and practices [35]. This model provides a framework for e-competences needed in a society in which technology is central to the life of its citizens and that should be a reference for teachers and educators in general to prepare students to thrive in this society. According to Redecker [67], the digital competences these professionals should develop fall within six specific working areas, depicted in Table 9.

Table 9. Skills and digital competences of teachers.

Professional engagement	Ability to use digital technologies to communicate, cooperate with colleagues and develop in personal terms.
Digital resources	Ability to identify, create and share digital resources.
Teaching and learning	Ability to use digital technologies in the teaching and learning process.
Assessment	Ability to reinforce students’ assessments through digital technologies.
Learners’ empowerment	Ability to use digital technologies for the learners’ inclusion and active involvement.
Enable learners’ digital competence	Ability to enable the learners’ creative and responsible use of digital technologies to communicate, create content and develop solutions for problems.

Source: Adapted from Redecker [67].

Given the new and ever-changing educational scenario presented above, educational institutions in general, and particularly higher education institutions (HEIs), are faced with the challenge of developing an approach that incorporates research, teaching, knowledge transfer and operations always based on ESD. This approach entails a transformation, not only of the governance of HEIs, but also of the processes, the members’ understanding of teaching and learning [68,69], and even, in the long run, likely the institutional culture.

In this new educational setting, new technologies are a strong source of support for the development of learning that promotes collaborative and group-work learning, as well as mobile and ubiquitous learning [12]. Smart classrooms promote and enhance individual active learning with the use of interactive resources that new technologies offer. Hence, smart education is built on an educational system centered on internet-based interaction between the educational actors and between them and the environment, developing an educational process that allows students to attain and/or to improve the transversal competences needed for them to succeed as students and future professionals [12].

The International Association of Smart Learning Environments (IASLE) defines smart education as a novel field combined with, for instance, smart technology, smart teaching and learning processes, smart education, smart classrooms, smart HEIs and smart society [70]. This smart education based on new technologies allows more efficient and easy knowledge and competences transfer to learners, while promoting active learning and broad communication between all educational actors, which enables the sharing of knowledge without the traditional time–space constraints [71].

According to Nezhyva [72], smart education follows a set of basic principles, detailed in Table 10.

Table 10. Basic principles of smart education.

Using up-to-date curriculum information for learning objectives	This entails the speed and volume of information flow. Moreover, professional activity is growing rapidly. Teaching materials should be complemented with real-time information on practical problem-solving in the context of real-life situations.
Organization of independent cognitive, research and project activities for students	This is paramount for developing in students the competences needed for searching for practical problems, independent information and research.
Implementation of the educational process in a distributed-learning environment	The learning environment is not limited to the HEI, whether in face-to-face and/or distance-learning systems. The learning process must be continuous and embrace training in professional environments using professional tools.
Flexible educational trajectories and individualized learning	Education is aimed not only at students but also for professionals who want to enhance their knowledge through continuing training. The HEI should provide educational services to meet the needs of those who wish to attain new knowledge or to develop their existing knowledge.
Student interaction with the professional community	The professional environment is essential in the educational process. Using ICT throughout the training process enables participants to better adapt to professional environments where ICT is central. According to student needs and capabilities, the HEI's task is to provide this sort of educational services.
Multifaceted educational activities	Depending on the institution's capacity, health, laboratories and overall conditions, these activities are excellent opportunities for those who wish to study in any training program.

Source: Based on Nezhyva [72] (p. 68).

The existence of Society 5.0, as a form of smart society based on digitalization, informs the potential for the implementation of smart education. In sum, for smart education to be adequately implemented, it needs to (i) ensure the existence of an up-to-date syllabus; (ii) foster students' autonomy; (iii) provide adequate learning environments; (iv) allow flexible and individualized educational trajectories for students; (v) promote broad communication between all actors involved in the teaching–learning process; and (vi) provide students with a wide variety of educational activities, both in terms of formal and informal learning, with the mobilization of this new technology and the shifts in the teaching processes.

In line with what Nezhyva [72] argues smart education should entail, Demir [73] (p. 3) defines this new educational approach as the "[. . .] effective and coherent use of information and communication technologies to reach a learning outcome using a suitable pedagogical approach". The authors stress that smart education goes beyond the use of new technologies and involves the adoption of new teaching and learning approaches, with students being autonomous, collaborative and experts in information and communication technologies, and teachers becoming facilitators.

Demir [73] argues that education is, currently, permeated both by new technologies and new ways of thinking and provides a comprehensive list of the main information technologies that enable smart education (Table 11).

Moreover, the author developed a Smart Education Framework, composed of several layers (Figure 8). The core layer regards the new or improved learning/teaching approaches (e.g., personalized learning and flipped learning). The second layer regards essential/transforming technologies that are critical for smart education. The third layer of the framework concerns enriching technologies, whose use in smart education enhances the educational process. Finally, the fourth layer regards supporting technologies, which are general-purpose technologies.

Table 11. Use of information technologies in smart education.

Learning management systems	Software applications or systems developed to create, communicate, manage and deliver educational programs.
Smart classrooms	Physical educational environments that use ICT. They may use ambient intelligence technology.
Virtual classrooms	Educational environments where the teaching and learning process occurs virtually.
Cloud computing technology	On-demand access to shared computing resources. The technology underlying this process is cloud computing technology.
Extended reality (XR)	All real and virtual combined environments, including augmented reality (AR), virtual reality (VR) and mixed reality (MR).
Virtual environments	Computer-generated environments that replace real environments with virtual ones.
Augmented reality	Technology that deals with enhancing the user's sense of the physical world with computer-generated sensory data in real-time.
Web 2.0+	Technologies that follow Web 1.0. These web technologies offer interactive, semantic and intelligent web services.
Social networks	Online platforms where users having profiles may interact.
Educational resources	Any type of learning and teaching material. They may be open to the public (open educational resources) or private to specific institutions.
Academic and corporate tubes	Online video-sharing platforms for educational purposes.
E-books and interactive books	Digital books enhanced with user-interaction ability.
Mobile technology	The information and communication technology that enables portable mobile devices.
Serious games	Computer games used for instructional purposes.
Learning and academic analytics	Learning analytics regards the collection and analysis of data about learning activities. Academic analytics uses business intelligence tools and strategies to support educational decision-making.
Educational data mining	Concerns analyzing data obtained from educational environments to understand patterns of learner behavior and improve educational settings.
Educational robots	Robots used in educational and training processes.
Gesture-based computing	Technology aimed at understanding human gestures.
Ambient intelligence	Emerging paradigm that brings intelligence into our lives with the help of intelligent interfaces and smart environments.

Source: Adapted from Demir [73] (p. 6).

This is not, naturally, a static model and may be adapted or customized to specific situations, topics or subjects. Furthermore, as new technologies emerge constantly, the ones presented in the framework are likely to change on a virtually daily basis.

For smart education to be able to fully develop, a (smart) educational environment is paramount. Moreover, such an education approach entails smart actors, namely educators and students, and smart educational intermediators [74]. The role of smart educators, as facilitators of the teaching and learning process, is to (i) organize and promote smart educational activities; (ii) design and convey adequate educational content; (iii) foster an appropriate educational environment; and (iv) regulate the smart educational process. This process needs, more than smart educators, smart learners who understand and embrace the process [74]. Indeed, in a smart education environment, learners have intelligent thought and are efficient in acting and solving problems in a student-centered, personalized, interactive and collaborative educational process [10,75].

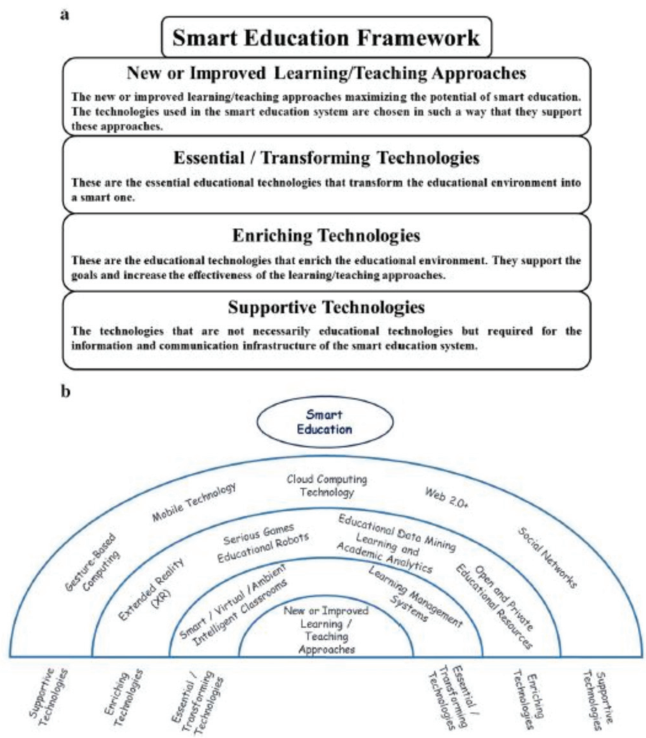

Figure 8. (**a**) Smart education framework layers; (**b**) Smart education technologies. Source: Demir [73] (p. 9).

Zeeshan et al. [10] put forth a set of goals that smart schools pursue and that bring them advantages when compared with traditional schools (Table 12).

Table 12. Some of the key purposes of a smart school.

Attain digital literacy and ICT-literate future professionals.
Achieve an interactive, collaborative learning experience and higher-quality education.
Achieve inclusive education by providing virtual education to remote areas without having to build physical school infrastructures.
Equip teachers with up-to-date teaching tools and applications to ease their work and enhance the quality of their work.
Attain sustainable resource management in quality education.
Achieve SDGs by supporting and building sustainable communities.

Source: Based on Zeeshan et al. [10] (p. 4).

It is, thus, critical that smart schools invest in teacher training, digital infrastructures, curricular change, improved teaching and learning methods, interactive and collaborative technologies, and learning environments that foster this new way of teaching and learning [10]. Moreover, according to Nezhyva [72], smart education aims, first and foremost, to develop in students the skills they will need in the future to be successful professionals that know their way in a digital society. To attain this objective, smart education needs to create learning environments that promote the students' continuous learning and development of competences, both in formal and informal learning processes.

However, the implementation of smart education faces some challenges, namely concerning the role of the teacher in the 21st century educational process [11,12,72], as well as the need for mindset shifts both in educational institutions and in their students [5,38,76]. Furthermore, the existing inequality in accessing education via digitalization aggravates the gaps in accessing information and knowledge. These gaps concern both the access to digital equipment and tools and the opportunities to develop the necessary competences to navigate in the digital environment [39]. One example of this digital divide is the lack of digital skills that many teachers still reveal, which is overcome by increased teacher training in this dimension, thus fostering sustainable educational development [77]. Thus, teacher training in both digital technologies and sustainability are paramount to empower teachers and provide them with the knowledge and tools that allow them to fully take on their role as vehicles of social change in sustainable development [5,10,72,74,78].

In sum, for education to become sustainable, all institutional actors (academics, students and non-academic staff) need to attain and/or develop digital competences, namely through the adaptation of training programs for the emerging educational digital needs [79].

Nusantoro, Sunarya, Santoso and Maulana [80] refer to the concept of a smart university as one whose processes are designed to meet the needs of the institution, and they make a distinction between a smart university and a smart city, detailed in Table 13.

Table 13. The six smart points of a smart university in terms of management procedures.

Smart people	The involvement of HEI users is much needed in the teaching and learning process and at certain events.
Smart management	Allows students and HEI staff to participate in joint decision-making.
Smart atmosphere	Environmental sector with smart solutions to sustainably manage available resources.
Smart entrepreneurship	Creates productivity and innovation to be implemented in HEIs.
Smart activity	All activities can be monitored for various life factors, namely concerning health, behavior and safety.
Smart movement	Discusses the best solutions for the implementation of systems in HEIs, e.g., environmentally friendly and efficient transportation.

Source: Based on Nusantoro et al. [80].

Considering the six smart points above, the authors sustain, thus, that smart cities and smart universities share many similarities in terms of management procedures, while having, naturally, particularities that are characteristic of educational institutions.

In their systematic literature review on the current state of smart education, Martín, Alario-Hoyos and Kloos [81] conclude that, while there is a wide array of publications on this topic, must of them use a theoretical perspective to address it. The authors identify some challenges facing smart education that need a more in-depth analysis, depicted in Table 14.

Table 14. Challenges of Smart Education in need of further research.

Connectivity	Tests performed in several smart education settings in terms of the speed of their communications revealed a high decrease in performance as more devices connect, which is a difficulty, as the trend is increasing numbers of students per classroom. This may be solved by the definition of a specific protocol for mixed communications, which could allow quicker response and/or the introduction of more elements into the systems.
Security	Smart education environments frequently collect personal data of students and teaching and non-teaching staff. Hence, further research should be developed concerning the ethical aspects of data collection, namely privacy and secure data management.

Table 14. *Cont.*

Prediction systems	Another pertinent research line regards the prediction of events before they take place, such as student dropout, to allow corrective measures and/or increase resources to improve teacher and student performance.
Data visualization	Further research is needed in terms of how to deal with the large amount of data generated in smart education environments, display them correctly and make this data easier to understand for institutional actors.

Source: Based on Martín et al. [81].

Once again, the issue of teacher training is pivotal in that it provides them with skills so that they are able to fully play their role as facilitators and co-creators of knowledge in a smart education system, namely through the use of innovative teaching practices [74].

Interaction is a core element in smart education and smart learning environments. According to Nezhyva [72], interaction in these educational environments takes on the following forms:

- Student–learning material. The student interacts with the learning materials;
- Student–teacher. Teachers help, stimulate and motivate students in understanding and mastering the learning contents they interact with.
- Student–student. Enables the development of communication competences. Communication occurs through a diversity of channels, such as e-mail or web-conferences, for example [72].

Guo et al. [74] argue that, through smart education, there are increased learning opportunities to achieve excellent education, lifelong learning and sustainable development, specifically covering the implementation of SDG 4 (Equal, life-long and accessible education for all).

Moreover, this comprehensive and all-encompassing smart education is a powerful tool in preparing future professionals inasmuch that, according to Zeeshan et al. [10], smart education must consider sustainable development in its economic, social and environmental aspects. According to the authors, it is critical to adopt a technology-based education system that intimately contributes to sustainability in terms of equity, equality, justice and quality. This is one of the basic principles of an education that, in addition to being intelligent and sustainable, adequately prepares and qualifies future professionals.

Nezhyva [72] sustains that the use of smart technologies in the teaching and learning process will foster the transition from the traditional education process, based on knowledge reproduction, to an entirely and novel form of teaching and learning through the use of innovative methodologies and the development in students of critical technological knowledge and transversal competences that they will have to mobilize in their future profession careers [72].

8. Conclusions

The main purpose of this paper was to critically discuss some aspects of Society 5.0, such as the dimensions of digitalization and sustainability.

The document analysis carried out allows for the conclusion that Society 5.0 is not an inevitability, and that the transformations it implies, alongside the advantages, also have challenges and limitations that should be considered due to the risk of reproducing old forms of micro, meso and macrosocial inequalities within each country and between countries and regions and, at the same time, creating new forms of social, cultural, economic and political inequalities, among others. A critical spirit seems to be necessary for monitoring this Society 5.0 and for which CS, in an interdisciplinary way, can potentially provide tools for prior and prospective analysis of its implementation in a scientifically informed society.

In summary, science and technology produce more robust and sustainable knowledge if they weigh their instrumental knowledge with other types of knowledge, such as, for example, critical political ecology, which promotes "[...] the social construction of all knowledge, supposedly neutral explanations of ecological reality and multiple discourses of sustainable development" [82] (p. 137).

This results in the importance of smart education, with its multidimensional interdisciplinarity [65,72], in promoting a learning process that is simultaneously efficient and effective. Furthermore, an increase in cooperation—both professional on the part of academics and in research on this pressing topic, mainly in the search for a more proactive attitude [65] in the creation of a Sustainable Digital Society—will result in smart education and a smart society.

This conceptual paper, which aims to critically discuss some aspects of the importance of the relationship between citizen science and smart education in promoting sustainability in increasingly digital societies through the promotion of smart education, resulted in the perception that the relationship between these concepts is still very tenuous and has yet to be explored by science. As a consequence, several suggestions for future research result directly from this analysis. Among these, we highlight (i) the need to study the role of interdisciplinarity in implementing the logic of citizen science in this process of developing smart education; and (ii) the importance of studying the emergence of new inequalities, as well as the possible reproduction of old inequalities that perpetuate the social reproduction cycle when social production is intended in inclusive societies. Action research, in its various modalities, may be a desirable instrument in the development and assessment of projects for the implementation of smart education for sustainability in scientifically informed sustainable digital societies.

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Article

Connecting Classrooms with Online Interclass Tournaments: A Strategy to Imitate, Recombine and Innovate Teaching Practices

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Abstract: UNESCO's Sustainable Development Goal 4 and new curricula around the world call for a better quality of education. Among the main challenges of improving quality is increasing the integration between disciplines and improving the preparation of students for the personal and work requirements of a smarter and rapidly changing society. For that purpose, we need to design new and effective didactic strategies. However, current classrooms are isolated. They practically never connect. This hinders the exchange of ideas. It inhibits imitation and recombination, the basic blocks of cultural evolution and innovation. In this paper, we analyze four online interclass tournaments that we have implemented in the last decade. This long-term view is crucial for estimating the sustainability of new teaching strategies. These tournaments are very uncommon lessons, where entire elementary or middle school classes interconnect synchronously and play an educational game. This increased interconnectedness is only possible thanks to digital communication technology. We found that these interclass tournaments are feasible to implement in schools; that they are a promising mechanism for teaching with an increased integration of disciplines; and that they facilitate imitation, recombination, and innovation of teaching strategies. Thus, interclass tournaments could be a feasible strategy to help innovate and improve the quality of education.

Keywords: STEM education; educational technology; sustainable development goals; online inter-class tournaments

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1. Introduction

Quality education is one pillar of the United Nations 2030 Agenda for Sustainable Development. To improve quality, there are several challenges. One challenges is greater integration across disciplines in K12 [1]. Another challenge is better preparation of students for global citizenship. We have to prepare them for the personal and job challenges of a fast-changing and smarter society [2,3]. This is because, on the one hand, teaching in a more connected way, and more related to real-life problems, can make education more relevant, more meaningful, increase motivation to learn, and improve student achievement [4,5]. On the other hand, students need a deeper understanding of the core ideas of each discipline. Integration across disciplines helps to achieve a profound understanding of each discipline. Thus, the call is to link concepts and skills learned from two or more disciplines, in order to gain more far-reaching knowledge and understanding. This, in turn, prepares students for a world of constant and enormously disruptive changes. In that world, a deeper understanding of the central ideas is critical.

Therefore, for a quality education, teachers need to learn to teach connected disciplines. They should help students learn core STEM concepts and develop STEM skills that promote connections, such as rigorous argumentation, problem solving, and modeling abilities [6]. They should help students understand core science concepts [7], such as patterns, information, conservation laws, data and modeling, the particulate nature of nature, energy and metabolism, and natural and sexual selection. Moreover, integration also means that STEM teachers should help students deal with key current national and global challenges, such as climate change, social inequalities, emotion and cognition, pandemics, and impersonal trust [3,5]. They should also help students develop oral and written communication and argumentation skills. Teachers should also help to develop and cultivate students' values, beliefs, attitudes, responsible citizenship, cooperation, and teamwork. In addition, teachers should make students' learning more meaningful and improve their preparation for the personal and job challenges of a fast changing and smarter society. They should do all this without hindering their teaching of each discipline.

One key integration strategy is teaching real world applications. According to [8] (p. 146), "Interdisciplinarity has gained the most ground in applied fields, where the assumptions and common methods of different fields can be brought to bear on the same substantive questions and outcomes". In the case of mathematics, an example is statistics. All disciplines are generating more and more data and at an increasing speed. This translates into an increased use of statistics in a growing number of disciplines [9]. Other examples are mathematical modeling [4,10,11] and computational modeling [12–15]. There are also contents and practices in computational thinking that are gaining increasing importance in industrial and consumer-oriented applications. Nevertheless, they do not yet have a place in the K12 curriculum. For example, agent-based modeling [13], machine learning [5], or natural language and image processing do not yet appear in the national curricula. These recent computational developments directly connect mathematics and computation with the social sciences, psychology, biology, and language. Here, there is huge potential for across discipline integration.

However, integration has several barriers. First, a significant proportion of students have poor understanding of the core ideas in the individual disciplines. Thus, for them, connecting ideas across disciplines is not straightforward at all [1,16]. This means that teachers are primarily concerned with teaching the core concepts of their discipline, and do not have time to spend exploring ways to integrate with other disciplines.

Second, the amount of knowledge in each discipline is increasing rapidly. There is a true explosion of ideas, methods, and results. Thus, there are strong pressures on the curriculum, to introduce new content in each discipline. This content is also new for teachers. For example, we now have proposals of new curricula with concepts of computational thinking and the introduction of machine learning concepts to statistics [2,17].

Third, the new concepts of each discipline are not always intuitive. Sometimes they seem to contradict our intuition or our previous knowledge. Teachers then have to invest time planning how to teach these new ideas. For example, in Bayesian reasoning, use of adequate representations is critical for true understanding [18,19].

Fourth, there is a clear division of labor at schools. This is the norm in the elementary schools in some OECD countries and is an increasing trend in the United States [20]. Teachers teach the discipline in which they have been educated. Even in traditionally closely related disciplines, such as mathematics and physics, teachers teach only one discipline. The only exception is in the first levels of elementary education. However, even there, the teacher does not make an integration across disciplines. Teachers teach each discipline as a world apart from the others. Teachers teach the two critical disciplines, language and mathematics, as if they had nothing in common. Today, with the development of computer science in the area of natural language processing, both disciplines are increasingly close; for example, in large language models (LLM) such as ChatGPT [21], which is having a great impact on society, and in particular on research and education. However, mathematics and language remain completely separate in the curricula and at schools.

Fifth, teachers need to learn how to teach disciplines with a much deeper integration between them. This is something new for most teachers. They were not educated in the teaching of several different disciplines, let alone how to integrate them. There are still very few instances of teacher education in integrating disciplines [22]. According to the National Survey of Science and Mathematics Education [23], only 26% of schools offered courses for teachers on how to integrate science, engineering, mathematics, and/or computer science. In a list of 16 types of course, integration courses were one of the least common.

Sixth, teaching is a very conservative profession; "pedagogical change offers the teacher little apparent benefit and a great apparent risk" [24] (p. 55). In addition, integration poses a high risk. Activities that integrate disciplines could be very motivational, but can hinder high-quality instruction that helps understand the practices and principles of each discipline [25].

Seventh, there is a lack of textbooks and materials with integrated disciplines [26]. For example, there are no math–biology or math–social sciences school textbooks. Moreover, in each discipline, the textbooks do not have much integration with other disciplines. Therefore, this lack of materials requires teachers to invest a great deal of time and energy in studying other disciplines, meeting and exchanging ideas with other teachers, and beginning to try out new classroom alternatives [26].

Eight, it is still not completely clear how mathematics taught according to the curriculum helps to gain a better understanding of other disciplines, nor do we understand how other disciplines help students in learning math [16].

Ninth, there is a "structural isolation" in the teaching profession. Teachers teach behind closed doors [27] (pp. 51–52). This structural isolation between teachers and the impenetrable walls between classrooms makes it very difficult to compare, imitate, and exchange educational strategies.

Finally, teachers do not receive feedback about cross-discipline integration from monitoring or evaluation systems. Typical teacher class observation protocols and teacher evaluation reports do not include information about integration. For example, IMPACT, one of the most used teacher assessments system in the U.S., is 50% based on the student score and 35% on classroom observations by the principal and subject-based expert teachers [28]. Additionally, each national or state test measures students' learning in just one discipline. They do not include knowledge that measures integration across disciplines.

Thus, discipline integration has several formidable barriers to overcome. It is a completely new challenge. In addition, we need to learn to implement it at large scale. This is a huge professional development challenge for teaching.

2. Literature Review

2.1. Cultural Evolution: Imitation, Recombination, and Innovation

A review of classroom practices shows that almost no change has taken place over the last century [28,29]. Teachers mainly teach teacher-centered strategies. Some teachers are very effective when using such strategies. For example, in the Programme for International Student Assessment (PISA), the top-performing Organization for Economic Co-operation and Development (OECD) countries use more teacher-centered teaching practices in mathematics than other countries [30].

To improve teaching that integrates disciplines, we need to research and understand how to design and manage communities of teachers that work together. These communities should focus on devising innovative classroom practices that promote interdisciplinary learning. This type of research is new to the field of education. The results of this research will be crucial to the success of classroom practices that promote integration across disciplines and strategies that integrate educational research with classroom practice [31].

To do this, one of the main difficulties is that current classrooms are isolated. Reference [24] compares a school to a nuclear power station. Since each component of a nuclear facility is causally interrelated with the others, it is much easier to trace the chain of events and thus pinpoint the source of any deficiency and correct it. Schools, on the other hand, have completely independent units (classrooms). What happens in one unit does not affect the others. They practically never connect or exchange information. There are very few opportunities for interaction with other classrooms. This situation hinders sharing ideas and strategies, as well as copying and recombining them.

One tends to think that the problem is how to implement strategies carefully designed by authorities and experts. However, cultural evolution processes need the active participation of a large community. Moreover, innovation and change emerge from thousands of people coming up with and interchanging ideas [32]. No one is really in charge. For example, in the history of the critical cultural evolutions of humankind, such as the jump from tribal to larger societies, they did it without anyone having a global understanding of how it all fit together [33] (p. 102). It is an incremental, bottom-up, and rather random process. It occurs as a direct result of exchange, imitation, and recombination, and not as an orderly top-down process developed according to a plan.

Additionally, the collective brain perspective suggests an optimal amount of interconnectivity. Too much interconnectivity is not always better. The diffusion of complex behavior requires a mechanism that goes beyond simple interconnection. Complex behaviors follow a different adoption mechanism than that required for simple ones. Two key components are reiteration and homophily. Reiteration means a high frequency of interactions between teachers and between classrooms. Homophily means that the interactions should be with similar teachers and similar classrooms. Thus, teachers should interact frequently, and those interactions should be between similar types of teacher [34,35].

In summary, to achieve high-quality education under Sustainable Development Goal 4 of United Nations Educational, Scientific and Cultural Organization (UNESCO), we need to facilitate and speed up mechanisms for developing new teaching practices that include cross-discipline integration. This is a deep cultural evolution process. It requires devising powerful mechanisms of intergroup connection, with the appropriate diffusion mechanisms. These should foster innovation and the dissemination of new strategies. We have to devise appropriate network topologies, closer to a fishing net than a fireworks display [36], which connects teachers and their classroom with other similar teachers and their classrooms. We need to design collective learning strategies that promote social comparisons, such as intergroup competition and intragroup collaboration [37].

We have to understand the mechanics of knowledge creation and mobilization. We should design ways to accelerate how teachers and schools identify problems and develop interventions and strategies [31,38]. Finally, we depend on the fact that we are smart because we have culture, not the other way around [39]. In this paper, we use the framework of processes of cultural evolution to study the creation of innovations and their diffusion through tournaments.

2.2. Lesson Study and Open Lessons

Teachers need well-tested strategies. This means, teaching strategies developed in the classroom, and tested with students with similar grade levels, demographics, and socioeconomic profiles. This is not a top-down process. Bottom-up processes may be very effective, more sustainable, and scale better.

A popular bottom-up practice is lesson study. It is a teacher professional development strategy created in Japan in 1880. It is increasingly widespread in Asia and the rest of the world [40]. It is a collaborative teaching improvement process. Its goal is to build strong and productive communities of teachers, who share and learn from each other. According to [28] (p. 181), when teachers work together, they create pedagogical capital. This is a scarce resource, because isolation is endemic in schools. On the contrary, lesson study involves teamwork. Several teachers work together designing, testing, and improving a lesson. This process accelerates the production of effective lessons and lessons that aim to develop higher-order thinking skills [41]. It is a collective intelligence strategy to develop better lessons. It also helps innovation, in order to introduce new lessons adapted for new challenges. For example, lessons with integration across disciplines and that are also cross-border, integrating classes from different countries in a lesson [42–44].

After the team of teachers develop and test their lesson, a teacher delivers it in public. In a school theater or gym, tens or hundreds of teachers actively observe this open or public class. Then, in the same place, the teachers analyze it. It is a large community of teachers observing and analyzing together a class on a key topic they have to teach and with students similar to theirs. It is a true collective brain in action.

Lesson study and open lessons are powerful strategies that promote collaborative work among teachers, who imitate and then improve these strategies. However, they have some constraints [45]. They require a lot of time from teachers. They have to coordinate, find a common time to meet and observe a classroom, visit other schools and review recorded lessons together. Another constraint is the lack of a constant comparison between classes, since there is no competition between classes. Intergroup competition is a core mechanism of cultural evolution [33]. It constantly forces teams to compare each other, and search for what works best; "It pushes against the within-group forces of cultural evolution, which often favor self-interest, zero-sum thinking, collusion, and nepotism" [33] (p. 360).

Contrary to other human endeavors, the lack of interclass competition in education is due, in part, to a noncompetitive culture. This is very curious, because there is competition in some popular school events. For example, in athletic and team sport olympiads, musical contests, and math and science olympiads. These are very popular in schools [46]. Moreover, intergroup competition increases intragroup cooperation [47]. Nevertheless, in schools there are practically no competitions or tournaments between entire classes for academic subjects. On the contrary, in all schools, there is a much stronger competition but of different nature. It is competition between students in the same class. It is the competition generated by the usual student assessments, grade point averages (GPAs), and intraclass rankings. This intraclass competition inhibits collaboration.

3. Materials and Methods

There are two great challenges for the dissemination of educational practices generated by activities such as interclass tournaments. On the one hand, the creation, dissemination, and sustainable adoption of educational practices is a slow process that takes several years. Therefore, this requires detailed observation of the evolution of the tournaments and their effects for at least a couple of years. On the other hand, interclass tournaments are not a common activity in schools. It is a very innovative type of event. Moreover, they are not simple to implement. Each one requires the synchronous participation of several schools. This is a major logistic problem. It requires the coordination of tens of schools. For this reason, we take advantage of the implementation of several of interclass tournaments, and the observations and studies that have already been carried out on some of them. This long-term view is crucial for estimating the sustainability of new teaching strategies.

Thus, the methodology consists of the reviewing of four different interclass tournaments that we have implemented over several years in the last decade. They are four independent tournaments, implemented in different schools and districts in Chile. In addition, they are tournaments with very different contents. One tournament is on machine learning and statistical modeling, another is on physics, the third is on word problems in mathematics, and the fourth is on natural selection in biology. These are interclass tournaments carried out in several grade levels of elementary and middle school. They share one key feature: they are online interclass tournaments. In all of them, different schools participated. In each one, we studied the emergence of the diffusion of interclass and cross-schools learning and teaching strategies and practices.

First, we describe the conceptual framework of intergroup play as an educational tool. Then, we will define the research questions, the methodological approach, and the materials.

3.1. Intergroup Play

Play is a natural educational strategy. Mammals and even birds play to learn [48]. For this reason, playing to learn has great potential for teaching and learning [49,50]. This explains the interest in educational games [51]. Play is the natural pedagogy. Thus, the proposed theoretical framework in this paper is play. However, a uniquely human type of play is competitive play between groups. This is coalitional play fighting between two or more groups. Intergroup play is very popular and is the basis of team sports. Ethnographic evidence from hunter-gatherers suggests that intergroup games are universal and have been a basic learning strategy in the evolution of human culture. Dyadic play fighting occurs in many species, but only humans engage in coalitional play fighting [52].

Additionally, the scale and popularity of some team sports, and the size of the entertainment industry based on team sports, indicate that we have psychological components that make them attractive and engaging to us. "Participation in team sports such as ice hockey and soccer provides many children and adolescents with their first experience of intergroup competition, which may have lasting psychological effects" [33] (p. 350). Moreover, "This shared experience seemed to create a collective sense of meaning and greater solidarity among the student body" [33] (p. 351). According to [33], team sports and sports leagues "placed nonviolent intergroup competition at the center of people's leisure time, where it often became part of their personal identity. Participation in team sports became central to raising children (well, at least boys)" [33] (p. 360).

There is a long history of using team-game tournaments (TGT) in classrooms for academic subjects [53,54]. For example, [55] proposed a TGT, in which each week students from one class compete against members of other teams from the same class. In one of the earliest TGT in mathematics, [54] measured the effect of a noncomputer based math game played within the classroom by teams. During the game, students received immediate feedback, while each individual's score was public. Low ability students achieved a significant improvement.

However, at school, the natural team is the class. Being in the same classroom for months and years creates a powerful sense of belonging and identity. Nevertheless, despite these facts, schools and teachers do not use interclass games for teaching.

Regarding tournaments, we can differentiate several types. There are the tournaments in which a selected member of the class participates. This is what happens in the typical math and science olympiads. These are excellent events for finding and training talented students. Another type is team tournaments. Here, each class selects a team, which represent the class, for example for a group discussion contest. This option recruits more students than the previous one, but sometimes it can create conflicts inside the class. There are conflicts about the number of teams, who makes up those teams, and who is left out. The third option is when everyone in the classroom actively participates together in one team. If this type of tournament is frequent, week after week, then there is a greater chance of learning for all the students of the class. This last type of tournaments is the one we study in this paper.

A benefit automatically provided by interclass tournaments is an efficient social dissemination mechanism. The frequently reiterated interactions between different schools enhance the probability of the diffusion of strategies. Moreover, the tournament designers can include a fishing net network topology between schools [36]. This type of networking facilitates the interaction between similar schools, and therefore facilitates imitation. This mechanism of social interaction can be more efficient than other community learning strategies. It can also accelerate improvement and innovation. Interclass tournaments simultaneously put a larger number of classes to work on a common activity. That is, a large number of students, teachers, and coordinators connect with each other. They then imitate more successful ideas and strategies. This is a great learning opportunity, since population size correlates positively with the number and complexity of innovations [32,56]. These tournaments also allow coordinating various groups that modify the activities. They test variants and adaptations of activities, in order to improve the teaching of core concepts and crosscutting concepts. Thus, interclass tournaments could also facilitate cultural evolution mechanisms for the innovation of new didactic activities that improve interdisciplinary integration. Moreover, interclass tournaments where all students participate create an environment that forces students of differing abilities to interact.

3.2. Research Questions

ICT makes it possible to implement online interclass synchronous tournaments, where students participate without leaving their schools. Teachers can also interconnect frequently with other teachers through the Internet. These experiences of frequent interconnection through the Internet between teachers facilitate the evolution of teaching strategies. For example, during the COVID-19 pandemic, in an Internet-interconnected community of teachers, we found evidence of imitation and improvement in didactic strategies [57]. This leads to the conjecture that for interclass tournaments there may be a similar process between teachers. In this paper, we consider two research questions:

Research question 1: To what extent is it feasible to hold interclass tournaments with topics from various disciplines, where all students learn the central ideas of each discipline and crosscutting concepts?

Research question 2: To what extent do interclass tournaments help to innovate and disseminate educational strategies?

3.3. Methodological Approach

In this paper, we analyze the evolution of four online interclass tournaments over a period of approximately a decade. For each of the tournaments, we previously carried out and published impact studies on student learning. In addition, we performed several studies on the effect of gamification on learning, which used the word problems game of one of the interclass tournaments. These were carried out in two randomized controlled trials [58,59], each one in different years and conditions. We have also carried out qualitative studies with semi-structured interviews with teachers, principals, and students.

The objective of this work is different from the abovementioned studies. Here, we do not study the effect on student learning. Instead, we focus attention on the evolution of tournaments and on the teaching practices for these tournaments. That is, the objective is to understand the cultural processes of dissemination of ideas and strategies, and the generation of innovations. For this purpose, we study the changes experienced over the years in teaching practices during the preparation for and participation in the tournaments, and regarding changes to the tournaments and the games that comprise them. These are changes documented in the interactions with teachers and students, and thereafter documented in specifications to software upgrades.

Changing practices is a very slow process. From the last century and the beginning of this one, teaching practices have changed very little, despite major transformations in educational policies [28]. According to Cuban, the appropriate educational metaphor is that educational policy changes are huge hurricanes, but that the classrooms are at the bottom of the ocean. Therefore, they have remained unchanged.

Cultural evolution does not occur easily, because it requires a population size and a minimum degree of social interconnectedness [60]. This is difficult to achieve in schools with isolated classes. Furthermore, the diffusion and generation of technical ideas such as innovations in algorithms are difficult to pass on [61]. Using well-designed experiments with several generations of imitation of artificial objects (images and knots), these processes can be detected [60]. For natural phenomena, such as educational practices, the emergence of innovations is more complex.

However, the controlled nature of tournaments, the number of schools involved in these activities, and the interconnectedness generated by online interclass tournaments facilitate innovation and the detection of certain changes, even when their evolution is a slow process. This detection is facilitated because these changes translate into very well-defined changes in the games. In the tournaments studied in this paper, the changes translated into software changes. These are changes in the software of the games and in software for the management of the tournaments. The tournament development team has documented these changes, as required by software management practices. The team had to describe the upgrades in precise specifications and discussed and revised them with software engineers. Furthermore, after each new software version, the tournament development team had to test the changes and make sure they agreed with the specifications.

Thus, the methodology followed in this paper considers monitoring the requests and implementation of software changes and the interactions with teachers that led to those changes. We concentrate on the major changes in the software releases. For each tournament, we summarize three type of change. First, we list the main misconceptions that teachers had detected. This is because the tournaments included important innovations in areas of knowledge that are not normally taught. Thus, these are concepts not well mastered by teachers. Being new concepts, in the tournaments, there was a learning process on the part of the teachers. They were discovering misconceptions that they were unaware of. These discoveries generated changes to teaching strategies and adjustments required to the games. Second, we summarize the main changes in teaching practices. Teachers discovered new strategies. Some of these strategies were more efficient than others. We list the ones that seemed more efficient. Third, we summarize the main requests for software changes or changes to physical devices. Not all the requests were implemented. Only the ones that seemed most promising. These included innovations in the games used in the tournaments, as well as some innovations in the management of the tournaments.

3.4. Materials

We used the data obtained from previous research on the effect on students' learning of four interclass games and tournaments for teaching integrated STEM [62–67]. These are four interclass tournament activities for elementary and middle school students.

One interclass tournament is for teaching machine learning and statistical modeling. A second activity is to teach the conservation of momentum in physics and its practical application in an engineering optimization challenge. The third is for teaching word problems, integrated with financial literacy. The fourth is for teaching natural selection and sexual selection in evolutionary biology, along with developing statistical and population thinking. In all these online interclass tournaments, there is some degree of integration between the science and mathematics curriculum. They additionally integrate meaningful engineering and technology challenges.

We review all four tournaments, looking for information on how teachers imitated and recombined strategies, and how the nature of the games used in the tournaments evolved with teacher feedback. Online interclass tournaments are a new type of academic activity unprecedented before the ICT age.

3.4.1. Machine Learning Interclass Tournament

This is a synchronous interclass tournament [62,63]. Our team designed this game in 1995 [62], and the first online interschool tournaments started in 2008 [64]. Players have to detect patterns. For each round, the platform shows a box of a certain size and color. The box is closed but inside it contains 12 cells (Figure 1). The box displayed in each round is the same for all classes. However, for each cell, the platform assigns black or white using hidden rules. For example, if the height of the box is larger than 6 cm and its color is yellow, then cell number 5 is white, otherwise it is black.

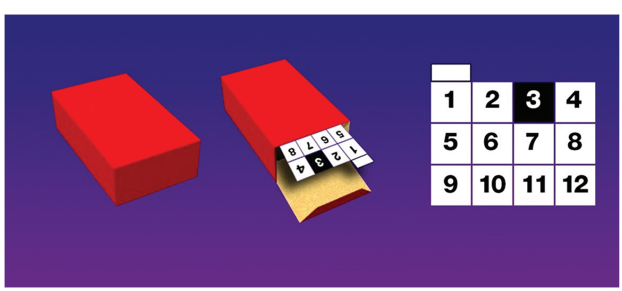

Figure 1. Closed box, open box with booklet inside, and booklet with 12 cells. In this case, cell 3 is black. The rest are white.

After watching the new box and studying patterns between boxes and cells in previous rounds, each player must bet on the color, white or black, of his corresponding cell. After 2 min, the time is over, and the box opens to display its contents. If the student's prediction is correct, he receives 2 points, if it is not, then he loses a point. Alternatively, each player can bet "gray", meaning "I do not know", and earn one point. Another option is betting by writing a model. This is a classification rule, typical of machine learning. If the rule predicts the right color for his cell, then the player earns 4 points. If the rule predicts the wrong color for the slot, then he loses 4 points. Thus, betting by writing a rule is appealing but also more risky because the loss is higher.

The platform displays the team's accumulated points and the national ranking. Students in the team have a different pattern detection problem than the rest of their team. However, all teams have the same set of pattern detection problems. This creates individualized accountability for each student. Since the time is short, the probability of having a team member solving the problem instead of the assigned student is very low.

Based on the grade level of the classes and the learning objectives of the math curriculum, the tournament coordinator selects the hidden rules. These rules define the complexity of the patterns. For example, in the fourth grade, the coordinator can use simple fractions for the hidden rules. For the seventh grade, he can use linear inequalities for the hidden rules. This game has achieved a high degree of integration between numbers, statistics, probability, and supervised machine-learning concepts. Additionally, in the preparation sessions before the actual tournaments, the teacher explains some real world applications. A typical example was diagnostics. The teachers suggested students imagine that the box represents a car motor. That the characteristics of the box—length, width, height, and color—represent characteristics or symptoms of the engine, such as hours of use, viscosity, temperature at which it boils, and color of the oil. The act of opening the box corresponds to opening the motor, and the white or black color of the cell corresponds to whether or not the motor is faulty. There are several other diagnostic examples.

3.4.2. The Conservation of Momentum Interclass Tournament

This is an interclass tournament of predictions and explanations related to conservation of momentum [65]. It was first implemented offline in 2013, and online in 2016. It consists of a first session in which students answer a pretest on basic knowledge of the physics of movement. Students then participate in a 90 min session with four experiments. Later, in a third session, students participate in a synchronous tournament.

The experiments are as follows (Figure 2): The first experiment is about predictions when jumping off a skateboard in various conditions, and then verifying by jumping in those same conditions. For example, the students have to predict whether the skateboard moves and to where, if the student jumps forward from the skateboard. In addition, the students have to predict what happens to the skateboard if the student jumps harder forward. Moreover, students have to predict what happens to the skateboard if the student jumps carrying a heavy backpack.

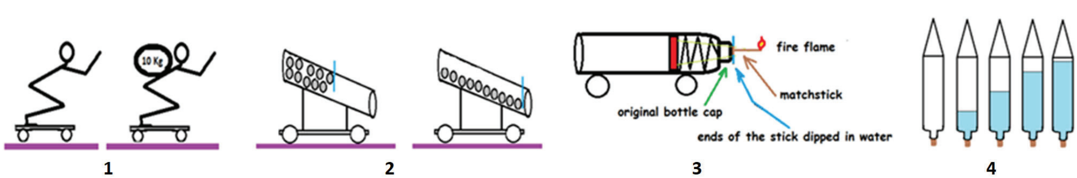

Figure 2. Experiments 1, 2, 3, and 4.

The second experiment is with a golf ball mounted on a toy truck and released by a slip. Again, students have to predict, and then verify their predictions. For example, the students have to predict what happens to the toy truck when the ball slides and falls to the ground. They also have to predict what happens to the toy truck if the angle of the slip is greater and the ball falls faster.

The third experiment is with a golf ball mounted on a toy truck that has a plastic tube mounted with an internal spring. When the spring is released, it launches the golf ball. As before, the students have to predict, and then verify their predictions. For example, the students have to predict the motion of the toy truck for different retractions of the spring.

The fourth experiment is with rockets made from disposable plastic bottles. Students fill a fraction of the bottle with water and then they pump air up to a specified pressure using a bicycle pump. They have to first predict and then measure the optimal fraction of water for the rocket to rise the highest. To carry out the measurements, they must make several launches with different proportions of water, ensuring that the pressure is always the same. An interesting problem is to devise some way to measure height or reach. Here, they can use knowledge of geometry. The students tabulate the data on paper or in a spreadsheet. In this way, the students can compare their measurements and find out how to synthesize the information using averages. Besides core science concepts, the activity promotes several math concepts that students must use. Among the main ones are fractions, measurement, statistics, and geometry.

In [65], we found that students who participated in the tournament learned significantly more than those who did not. Students with weak academic performance who participated in the tournament improved the most, reducing the gap with the academically stronger students.

The interclass tournament ends in a synchronized online activity. It is an online synchronous test. It contains questions that ask for a deeper understanding of the experiments. For example, it asks for an explanation of how the rocket rises, what is the optimal fraction of water, and their predictions with analogous reasoning using the skateboard and the toy trucks with slips and springs throwing golf balls. An interesting challenge is to explain why the optimal fraction of water is close to a third, and not the extremes.

3.4.3. Word Problem Interclass Tournament

In this tournament, students play a computer-based board game [66]. Its objective is to improve performance in word problems, which is a great challenge in mathematics education [68]. Our team designed the game in 2002 and started to use it for online interclass tournaments in 2014. Each player plays against a student from another school in a sequence of alternating rounds. The score of each student adds to the score of her class. The student has three beads to run through a spiral path of cells (Figure 3). The path ends at the center of the board, where the goal is located. On each turn, the student moves a lever that activates a raffle, from which a word problem randomly emerges. The solution to the word problem is the number of positions that the player has to move one of her three beads. The player chooses the most convenient bead. If she moves an incorrect number of positions, she loses points. If, after moving the bead, it ends up in a cell containing coins, then she wins the corresponding amount of points. If her bead arrives at a position with a springboard with a number, then she has to move the bead forwards or backwards the corresponding number of positions. If the bead ends up in a position with a trap then her bead goes to the start cell. If her bead ends up in position containing one of their rival's beads, then that rival's bead goes back to the start cell. Therefore, the player has to select which bead to move in order to maximize her gain. The player that reaches the goal cell first obtains extra points and the play is over.

All players play synchronously. The tournament coordinator announces the school ranking every 5 min. He sends this information in real time by video streaming. Each class projects the video streaming announcements in front of the classroom and using loudspeakers with a high volume level, to create a tournament atmosphere.

During the game, the student has to solve several word games selected according to the learning objectives of the curriculum. In each round, the student also has to make strategic decisions to maximize her gain and minimize her opponent's gains. The platform keeps the number of times the student solved the word problems correctly. It also knows the decisions the student used to maximize her gain.

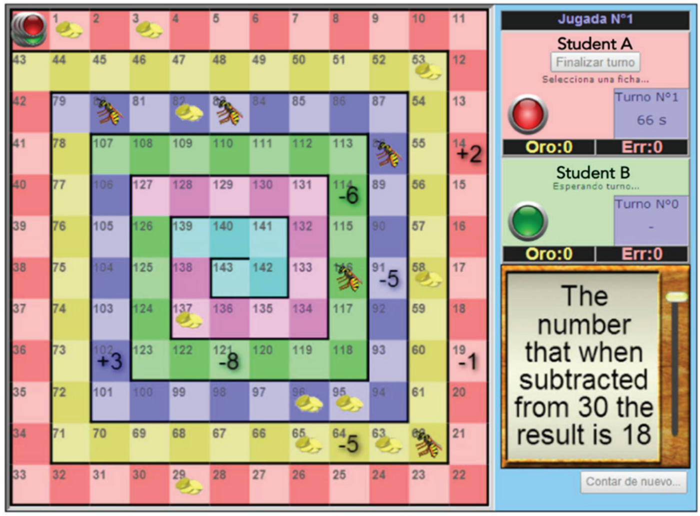

Figure 3. Screenshot of the board of the machine-learning game.

We found an important social facilitation effect: a significant improvement in the performance of male students weak in math, and therefore a reduction in the performance gap between mathematically weak and strong male students. Female students weak in math also had a significant gain, but this was lower than the one obtained by weak male students.

3.4.4. Natural and Sexual Selection Interclass Tournament

This is a synchronous interclass tournament [67]. We designed the first version of the game in 2009, and started to use it for online interclass tournaments in 2012. It involves organisms belonging to three species, each of which is a different color. The species of red color feeds on the green species, which in turn feeds on the blue species, and the blue species feeds on the red species (Figure 4). Thus, the three species form a nontransitive cycle. At the beginning of the game, the platform randomly assigns a species to each team. It also assigns to each student of the team a herd of four organisms belonging to the team's species. Different teams can have organisms of the same species, but the game assigns organisms, so that initially all species have an approximately equal number of organisms. The game has several rounds. Each round corresponds to one generation. During the tournament, students play six rounds, which takes a total time of 60 to 90 min.

In each generation, the organisms live a maximum of 20 virtual days. They autonomously move, chasing prey and avoiding predators. They do this according to their six innate traits, inherited from their parents, and to the instructions given to the whole herd by the student that owns it. On the one hand, each student, just before starting a round, specifies four parameters for her herd. For this, she uses four continuous sliders. The parameters are aggressiveness, exploratory attitude, punishment of uncooperative behavior, and imitation of the more energetic organism of the same species. On the other hand, all the innate traits of the organisms are binary: vision (short, long), velocity (slow, fast), ability to feel fear if close to predator (on, off), ability to feel hunger (on, off), ability to detect the remaining energy of prey (on, off), and cooperativeness (on, off). The platform graphically displays all of these traits. Players can detect them by visual inspection. Furthermore, there are filters or digital inks with which the player can stain the organisms, and thus she can easily count traits in the populations.

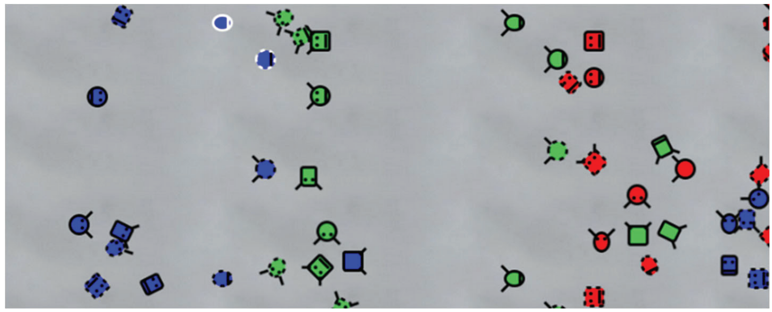

Figure 4. Part of the screen with the organisms of the three species. The ones with white border are organisms that belong to the player. Those with a continuous border are male and the others are female.

At the beginning of each round, players must make two predictions about the distribution of two features in the two species. The platform randomly assigns to each student the traits and species to track for the entire game. They are different from those assigned to other team members. Both trait predictions are about the proportion of the trait in the assigned species at the end of the generation. In addition, each player must make a binary prediction about the growth (increase, decrease) of the size of the population in each species. These predictions are a critical part of the educational aim of the game.

At the end of each round, each player has to select a sexual partner for each one of her female organisms that survived the round. For each female organism, the platform displays a list with the five nearest male organisms. Once the student selects a male, the platform creates an even number of offspring: half goes to the owner of the female organism, and the other half goes to the owner of the male organism. The number of offspring is proportional to the energy accumulated by the female at the end of the 20 virtual days. The offspring inherit the traits from their parents, according to a matrix unknown to the players.

The score of the team is the average of the score of its members. The score of a player is a mix between the agreement of the predictions and the size of the player herd. Every five minutes, the tournament coordinator announces the class ranking, in order to create an exciting tournament atmosphere.

One objective of the game is to promote population thinking [69]. This is a particular and powerful way of thinking in evolutionary biology. This means that the students have to learn to rapidly inspect swarms of organisms, observe their traits, perform data analysis and build models [70], detect patterns and tendencies, estimate the cost and benefits of the traits, use those estimates to make predictions, and then contrast those predictions with what really happened, in order to improve for the next round. We analyzed the performance of 181 students from 7 classrooms, where students took a pre- and a post-test on natural and sexual selection. The results provided preliminary evidence of the learning of key components of natural selection.

This interclass tournament has several additional components. It is a game in which all the players are in the same space. Therefore, the interaction and complexity is much greater. It requires the mind reading of many more players. In addition, the player has two different types of control: those that directly control the organisms' features, and those where the manipulation is through sexual selection.

4. Results

As proposed in the Methodological Approach section, we studied three phenomena. The detection of misconceptions, the introduction of some new teaching strategies, and some ideas for improving the games and tournaments.

4.1. Results of the Machine Learning Interclass Tournament

Throughout the years, together with the teachers, teachers identified several misconceptions in this game (Table 1). First, sample size neglect is common in students believing that with the results of one or two boxes they already have a pattern. Second, given the random selection of the boxes, there cannot be a pattern over time of the color of the cells besides the proportion of white and black cells. Even so, many students search for these types of patterns. For example, the sequence of white, white, black, white, white, does not implies that the next will be black. Third, there are salient features such as the color of the box. Many students believe that this is why it is a good feature for prediction. Fourth, the accumulated base rate is a good clue, but students ignore it. They tend to use just the outputs of the last turns. Fifth, many students believe that there is only one feature that discriminates. They do not explore the conjunction of two or more features. Sixth, there are also many students who overfit and do not test their hypotheses on independent cases.

Table 1. Main detected misconceptions, new teaching practices introduced by teachers, and innovations in the machine learning interclass tournament generated by suggestions from teachers or from interactions with them.

Misconceptions	New Teaching Strategies	Tournament Innovations
Sample size neglect	Record data in tables	Decimals and fractions
Temporal patters	Number line graphs	Bets with rules
Salient features	Record hits and misses	Decision trees in rules
Base rate neglect	Two dim scatter graphs	Rules with inequations
Single discriminator	Align features and classes	Gray bets
Independent test neglect	Check common features	Scoring strategies

Teachers have introduced some teaching strategies to improve the performance of their students. Due to the interclassroom competition, teachers were very interested in how other teachers were training their students. They wanted to know which graphical representations were better to allow a deeper comprehension and allowed faster and more accurate solutions. Some of the main strategies were the following (Table 1): First, teachers designed instructions to help students manage the incoming data and do this efficiently. This means, how to record the information, arranging it into tables where each row corresponds to a new box with its features. Second, they started to instruct students to draw one number line per feature and place on it the boxes' features and the contents of the included cells. Third, they started to give instructions on how to record hits and misses, and how to graph them on the number lines. Fourth, they started teaching how to draw scatter graphs of attribute pairs and how to do this quickly. Fifth, teachers sought strategies for students to align features of the boxes with the color of the corresponding cell. This seems trivial, but it is not for elementary school students. Sixth, teachers designed strategies for students to quickly verify with others the common characteristics of the features, and thus avoid or rapidly identify errors in records, tables, and graphs.

In the process of implementation, over the years, the tournament has changed. Several innovations emerged (Table 1). First, based on students' and teachers' feedback, we adjusted the learning objectives according to the grade level. For example, we introduced decimal numbers and fractions in the features of the boxes. Second, from the interactions with teachers, the idea of including models emerged. This skill was new in the math curriculum, and teachers wondered whether this activity could help to develop modeling skills. Teachers suggested a didactic strategy where the models were autonomous bots and students have to design efficient bots. The task of the students could change to designing bots. Thus, we built a rule design interface. The interface also included the facility to bet with rules. It took the form of selecting variables and adjusting rules. We performed several cycles of improvement, based on the ideas that teachers copied from each other, adjusted to their classes, recombined, and suggested to us. Third, we also introduced decision rules to the interface to design rules. Fourth, we introduced linear equations and inequations to the interface. This means rules with inequations. This was particularly important for middle and high school students. Fifth, we added a gray bet. This means "I don't know". This is appropriate for the initial turns of the game. Sixth, we introduced different scoring systems better adjusted to the grade levels and concepts of the curriculum.

We found that there was a great learning opportunity in the idea that students bet by writing rules. The rules use several learning objectives of the curriculum, such as a mix of categorical and numerical attributes, inequalities, scatter graphs, and linear and nonlinear equations and inequations. These changes were signs of a process of cultural evolution that was emerging in the community. In addition, analyzing students' behaviors, in [63], we found evidence of a diffusion process of strategies. Students learned different modeling strategies from other students, at least in the case of simple patterns. A statistical analysis [63] suggested that during the preparation for the tournament, some teams learned how to detect patterns, how to express them with rules (models), and then internally diffused those strategies. Students were successful in sharing only the simplest types of hidden input–output patterns.

In summary, we observed a diffusion process throughout classrooms in the tournament. Through feedback from teachers, we incorporated pedagogical instructions and adjusted the user interface of the game to promote learning. Additionally, we introduced the idea of autonomous bots, where the students had to design efficient bots. Through cycles of improvement, we observed a process of cultural evolution emerge in the community, with students using categorical and numerical attributes, inequalities, scatter graphs, and linear and nonlinear equations and inequations.

4.2. Results of the Conservation of Momentum Interclass Tournament

There are several well-known and documented misconceptions regarding basic physics. For example, that heavier objects fall more rapidly. However, there is not much experience in teaching the notion of momentum, also called quantity of motion. Therefore, misconceptions about this topic are not that well known. The left column of Table 2 lists some misconceptions that the teachers identified. First, students' notion of forces are the typical of horizontal motion of a vehicle in an environment with high friction. Someone has to be pushing the vehicle. Second, related to the previous point, they do not systematically include inertia in the predictions of motion. Third, they only include visible forces in their analysis. For example, someone or a motor is pushing the vehicle. The question is then how the rocket elevates if no visible force is pushing it. At this moment, students think of initial impulse and start to consider inertia. Fourth, they do not include mass in the quantity of motion. They tend to think initially that heavier objects moving at the same velocity do not have a higher momentum. Fifth, they think that more water inside the rocket means more energy, which helps to elevate it. Sixth, they think that motion is due to the initial impulse. They do not consider that the water continues leaving the rocket, or they do not know how to consider this effect.

Table 2. Main detected misconceptions, new teaching practices introduced by teachers, and innovations in the conservation of momentum interclass tournament generated from suggestions from teachers or from interactions with them.

Misconceptions	New Teaching Strategies	Tournament Innovations
High friction physics	Do measurements	Model with skateboards
No inertia	Compare measurements	Model with toy carts
Only visible forces	Draw experiments	Model with springs
No mass in momentum	Analogic reasoning	Trigger mechanism
Impulse from water	Explain verbally	Pressure meter
Only initial impulse	Modeling	Change rocket performance

Teachers also introduced several teaching strategies. The center column of Table 2 lists some of these strategies. First, teachers started to put more time and emphasis on measurements and to give instructions on performing more measurements with more precision. For example, measurements of displacements. Second, they also promoted making comparisons of measurements obtained by different students, finding the sources of errors, and finding options to control errors. Third, they suggested students draw the experiments and the setups. Figure 5 shows a sample of a fourth-grader drawing. Fourth, teachers promoted analogic reasoning. For example, imagine that the air inside the bottle was something like a spring mounted in the cart, and that the water was like the ball that the spring pushed once released. Fifth, teachers asked students to verbalize the explanations and compare the explanations of the different students searching for new ideas. Sixth, teachers started to talk about models. Where the different experiments were models that helped in understanding the motion of the rocket.

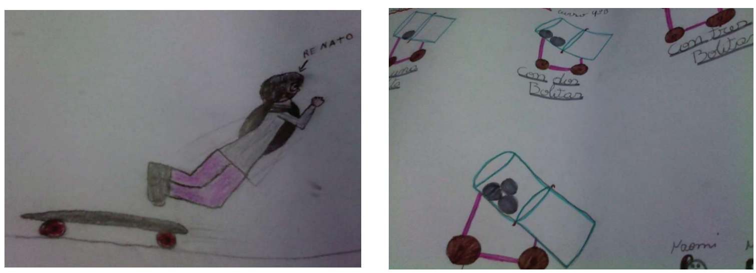

Figure 5. Drawings of the experiments by fourth-graders.

As we implemented these activities, the teachers gave suggestions to make them closer to the curriculum, to make them more attractive to students, and to facilitate their implementation in the classroom. The teachers were interested in knowing how other classrooms implemented the activities. How much were those students learning? How did those students do on the post-test? What were the differences with their students? Why did the differences occur? Teachers copied the most successful teaching strategies and recombined them. Thus, the experimental activity underwent several changes. Initially the activity was mainly launching rockets. Then, we started to introduce a explanations section to the tournaments. Then, with suggestions from teachers, we introduced several innovative experiments. The goal was to help understand how the rocket elevates. First, among the important innovations was the model with skateboards and with different weights in the backpack. The idea was to understand the role of mass in addition to velocity. Second, came the innovation using toy carts with balls. Third, we introduced the spring to push the balls instead of using gravity. This way, the balls gained velocity. Fourth, there was an interaction with students' fingers. Therefore, there was a need to have a trigger mechanism isolated from other interactions. Then, after several trial and error developments, a spring release mechanism emerged. The idea was to use a string that holds the contracted spring and set it on fire with a match. The fire moves slowly and burns the string until it cuts it. This causes the spring to loosen. This phenomenon generates a lot of expectation. This causes great excitement in the students, as it resembles a bomb fuse. Fifth, we introduced the measurement of pressure while pumping air. We instructed releasing the rocket at a given pressure. Sixth, we changed the performance score for the rocket. We incorporated launching the rocket at a certain angle (45 degrees, for example) and not straight up. This makes measurement easier. Another idea that emerged was to improve safety with skateboards. Initially, it was easy for some students to slip, which can lead to accidents. Over time, various didactic strategies emerged to maintain a certain level of order in the class and achieve the participation of all in the experiments.

Thus, teachers made various adjustments to the experimental activity to make them more engaging, closer to the curriculum, and safer. These adjustments created a lot excitement in the students and improved the maintenance of order in the classroom. The teachers also discussed how other classrooms implemented the activity, the learning outcomes, and the differences in learning between their students. In this way, they copied and recombined the most successful teaching strategies.

4.3. Results of the Word Problem Interclass Tournament

The synchronized interclassroom competitions not only attracted the students, but also the teachers. The tournaments encouraged the search for strategies to teach how to efficiently solve word problems and strategies for moving beads on the board. There was a process of comparison and imitation among teachers. Then, each teacher adapted the didactic strategies to the reality and level of her course.

This process of imitation, recombination, and diffusion of didactic strategies allowed us to improve the tournaments. It also led to an increase in the number of students who were attracted to solving the word problems and to do it with greater accuracy and speed.

Teachers identified and discussed between them and us different misconceptions about the word problems. Table 3 lists some of these. First, students automatically assign an addition to the presence of the word "more". However, this is not always true. For example, in "How much more is 12 than 8?", the student has to subtract. Second, the same happens with the word "minus". For example in "What number minus 3 equals 1?". Third, something similar happens with "division". For example, you have two bacteria. After they divide, how many do you have? Fourth, there is a strong impulse to use all the numbers mentioned in the question. Fifth, word order is not important. For example, they think that the square of the successor of a number is the same as the successor of the square of a number. Sixth, fractions are processes not numbers. Therefore, they do not have a position on the number line. Seventh, multiplication increases. This could come from the idea that multiplication is repeating. However, we can have repeating half a time or turn. Eight, division decreases. This idea may come from the fact that dividing is dividing equally. However, if we use the idea that dividing is how much the result fits into the dividend, we can see that half a sack of flour fits twice in a sack.

Table 3. Main detected misconceptions, new teaching practices introduced by teachers, and innovations in the word problems interclass tournament generated from suggestions from teachers or from interactions with them.

Misconceptions	New Teaching Strategies	Tournament Innovations
Always more means +	Pattern of word problems	Include word problems
Always minus means −	Search for metaphors	Include irrelevant numbers
Always divide means:	Use a concrete case	Include fractions in words
All numbers have to be used	Thinking with balls and boxes	Include fraction operations
Word order is not important	Check solution is integer	Include translations
Fractions are not numbers	Additions as translations	springboard sequences
Multiplication increases		How many times does it fit?
Division decreases		Financial elements

Teachers tried various teaching strategies. First, the most common was to detect patterns of problems and teach how to solve those problems. Second, teachers tried to use metaphors or analogies. For example, in finding the number that when subtracting 3 from it the result is 5, the strategy is to locate the position of 5 in the number line and then look for the position to place a small object that when moving it to the left 3 positions the object would reach the position of 5. Third, the teachers developed various strategies to translate to specific cases. For example, how much more is 8 than 6, translates into putting 8 blue candies in a row and comparing them with 6 red candies in a row, then putting them in pairs blue and red, and then counting how many candies remain unpaired. Fourth, thinking with balls and boxes. For example, for the number that when subtracting 3 gives 5, it can be thought of as a box with sweets that when removing 3 sweets is left with 5 sweets. Then the idea is to reverse the actions. Fifth, check that the solution is an integer and not a decimal, since then you have to move one of the beads in an integer number of positions. Sixth, imagine addition and subtraction as translations on the number line.

This tournament evolved incorporating several innovations radically different from the original version. Each player does not respond or advance independently of the others, as in a race, a pattern bet, or a knowledge test. Now, the student must make decisions taking into account what her opponent can do. Thus, in this tournament, there is a phenomenon of mind reading. Each student has to guess what her opponent will do. In the language of game theory, it is a true game. On the one hand, the word problem comes out randomly, but according to the learning objectives of the curriculum selected by the tournament coordinator. A solution is always a number between 1 and 20. These are the number of positions that the player can advance. However, next comes the risk factor. The student has to choose which bead to move. In certain positions, the opponent can more easily attack him, and there are others where he can attack his opponent more successfully. On the other hand, there are movements that have a greater benefit than others do. There are more coins to collect. This combination of chance, deterministic problems, mind reading, risk, and reward establishes a connection with the world of financial decisions.

Over the years, this tournament has undergone several significant changes. In the beginning, there were no word problems. Originally, teachers used the game for students to practice basic math concepts. For example, counting and arithmetic operations. However, some teachers suggested looking at how to include other learning objectives in the curriculum. One of the most demanded was the resolution of word problems. Given the attractiveness of the game and the students' weaknesses in solving word problems [68], we worked with some teachers on different strategies to include them. We tested on several classrooms. A second innovation was to introduce superfluous numbers, in order to signal to students to try for more comprehension. Third, we incorporated an increasing number of learning objectives from the curriculum and adjusted these to the strands and grade levels. An important topic in the curriculum and one that represents a great teaching challenge is fractions. We introduced fractions as words. This means expressions such as one out of four. Fourth, we also introduced operations with fractions. In the game, by its nature, the result must be an integer from 1 to 20. This is an important restriction. Fifth, we introduced additions as translations with trampolines on the board. Sixth, we also included the option to detect strategies with springboard sequences. Seventh, we introduced problems asking how many times one quantity fits into another. At the suggestion of teachers, we also included elements of a financial nature that support new learning objectives in the curriculum.

4.4. Results of the Natural and Sexual Selection Interclass Tournament

During the more than 10 years of implementing this game, teachers have detected various misconceptions. Many of them are known in the literature on the teaching of natural selection. However, the teachers were unaware of these misconceptions. One explanation for this is that teachers do not teach natural selection or sexual selection. They only teach the evolution of the species very superficially, without emphasizing the underlying mechanism. Table 4 lists the main misconceptions. First, students have a strong essentialist bias, where things have a true underlying nature, and therefore species have fixed essences. This essentialist bias can distort judgments about a wide range of evolutionary phenomena, such as the concepts of variation, inheritance, adaptation, domestication, speciation, and extinction. Second, students believe that organisms change because they need to change to survive. They do not conceive of it as a blind mechanism, completely independent of the needs or will of an organism. Third, students think that natural selection only operates on physical traits. Fourth, students and teachers think that Darwinian competition is incompatible with cooperation and altruism. Fifth, students think that natural selection explains the appearance of new traits, not the loosing of traits. Sixth, students think that the competition in natural selection is against other species, not of organisms within the specie. Seventh, students have a teleological view of evolution and have severe difficulties in understanding the blind mechanism of natural selection. Eight, students think evolution is progressive. These misconceptions are deep-rooted and not easy to eradicate. Thanks to the game and the tournaments, the teachers began to place emphasis on teaching the mechanism of natural selection, and therefore they began to detect these misconceptions.

Table 4. Main detected misconceptions, new teaching practices introduced by teachers, and innovations in the natural and sexual selection interclass tournament generated from suggestions from teachers or from interactions with them.

Misconceptions	New Teaching Strategies	Tournament Innovations
Essentialism	Population thinking	Behavioral traits
Organism needs to change	Graph histograms	Concrete to digital
Only physical traits	Blocks for histograms	Loss of traits
Cooperation is impossible	Trends in histograms	Sexual selection
No loosing traits	Cost–benefit tradeoffs	Graphs
Competition across species		Instructions to herds
Teleological conceptions		More generations
Evolution is progressive		Predict traits distribution
		Rock–paper–scissors ecology

During the years of implementation of the tournament, the interaction with teachers facilitated the development and implementation of various teaching strategies. The first was to promote population thinking. The idea is always to reason about a population of organisms of a species and not about single individuals. Second, the teachers began to train the students to construct histograms with the distribution of traits in the population. This was not common in biology classes. Third, for elementary school students, teachers began using plastic blocks to make histograms of traits and then translated them into graphed histograms on paper. Fourth, teachers began to instruct on how to visualize trends in traits across generations. Fifth, teachers began to promote reasoning about cost–benefit analyses and tradeoffs of the different traits.

We introduced several innovations during the years of implementation. During these years, teachers gave various feedback to the game development team. In the first years, the tournament started as a game between teams within classes. It was not computer-based but used only concrete material. In the first two versions, students played a game of natural selection of physical traits. The first version was about the natural selection of color. The second version was about the natural selection of beak size. After these successful experiences and the feedback received from several teachers and their classes, we developed a natural selection game of a non-physical trait. This was the first conceptual innovation. Introducing behavioral traits generated a fertile discussion among teachers. In the teachers' training and in the years that they taught biology, they had done very little instruction on natural selection, and if they included it, it was only of physical traits such as height or hair color. Therefore, the introduction of behavioral traits generated confusion among teachers. However, after successive cycles of trial and error, the conversation turned to how to teach the evolution of behavioral traits. Some teachers suggested starting by illustrating common behaviors close to students' daily life. This included the domestication of dogs and horses. Professional breeders artificially selected them. In other words, the behavioral trait was aggressiveness. Another behavioral trait introduced was cooperation. Students used hooks, some one-sided and others two-sided, with hooks at both ends [13]. The hooks represented birds. The hooks hunted fishes, represented by Christmas baubles. One-sided hooks fished alone, whereas two-sided hooks could hook onto each other, in order to reach the baubles that were deeper down. The second innovation was the development of a digital version of the game. The digital version facilitated holding interclass tournaments. The third innovation was the introduction of the possibility of losing traits. The fourth innovation was the introduction of sexual selection. This is difficult content and most teachers do not teach it. Students have male and female organisms, with the typical reproduction conditions of mammals. Human females mostly have only one child at a time, but males can have many. Students have to select mates for each of their organisms. The fifth innovation was the displaying of graphs in the game. The number of traits of the organisms increased considerably. Thus, students needed a lot of time to graph. Therefore, we introduced the facility to select variables and the game automatically displayed the graphs. Students had to rapidly interpret the graphs and use them to make decisions. The sixth innovation was the introduction of a facility to give instructions to the herd. Thus, each student has four control variables defined at the birth of the generation. The seventh innovation was to increase the number of generations. The greater number of traits and the number of control variables other than sexual selection made it difficult to see trends in three generations available in the original game. The eighth innovation was the facility for predicting the distribution of traits. Since there are six traits, each student predicts a pair of traits. Therefore, that is 15 combinations of different pairs of traits. Each student receives a pair to predict. Thus, in a typical course there are only two or three students who must predict the same pair. The ninth innovation is the introduction of rock–paper–scissors ecology [71]. One of the questions that arose was whether generations could exist in a nontransitive relationship. In other words, species A preys on species B, species B preys on species C, and species C preys on species A. This led us to include three species in this rock–paper–scissors relationship.

With the interclass competition, teachers became interested in knowing how teachers from other sections or schools introduced these ideas. They also wanted to know the responses and learning of the corresponding students. There was copying of concrete materials, stories, and teaching strategies. Natural selection is one of the central themes of biology. It is a great challenge to develop and learn effective teaching strategies that manage to dismantle deep-rooted misconceptions. Then, we developed an online version with many more features, both physical and behavioral. The feedback from teachers and students guided the inclusion of game features. This is an example of a cultural evolution process of multiple micro-adjustments and innovations throughout years of interactions.

In summary, the teachers gave various feedback to the game development team on introducing behavioral traits, such as aggressiveness and cooperation, into the game. Their experience with natural selection was limited and it was restricted to physical traits. Sexual selection was also not part of their instructional goals. Through trial and error, they discussed strategies to exemplify common behavioral traits in domesticated animals. We used the feedback of teachers and students to guide the development of an online version of the game with these more challenging and deep concepts. Teachers learned from each other what worked best. This is an example of a cultural evolution process, guided by multiple micro-adjustments and innovations over time.

5. Discussion

According to UNESCO's Sustainable Development Goal 4, by 2030, we have to ensure that all learners acquire the knowledge and skills needed for global citizenship. In particular, a great challenge is learning to integrate disciplines. Another challenge is to learn to cooperate with known and unknown people. However, classrooms are isolated from each other. This generates very little cooperation between teachers. A way to try to achieve more integration and collaboration is with effective learning environments. In this paper, we reviewed how feasible it is to connect classrooms with the help of technology and hold tournaments between classes. Does this facilitate collaboration and the dissemination of effective practices?

According to [72], in cooperative learning, the most important element is positive interdependence; students should believe that they sink or swim together. With synchronous online interclass tournaments, there is a common goal. All students share this common target. The platforms explicitly highlight this key element by posting class rankings as students compete against other classes. The platform permanently publishes the class score, reminding students of the shared target. Another key element is individual and group accountability [72]. In these four types of tournament, the platforms track the performance of each student. The games also includes instant feedback and metacognition. For example, in training sessions, the teacher can freeze the game, as in basketball games, and can pose open-ended questions that promote a deeper reflection. The teacher thus becomes a coach, constantly providing cognitive and emotional support to the class.

From the teachers' point of view, they quickly build a community that remains highly connected throughout the tournament. Teachers discuss their strategies with tournament organizers, as well as with other teachers of the tournament community.

Additionally, the coordinator of the tournament also has a fundamental role in promoting metacognition. This role is particularly intense in training sessions. She comments on the strategies developed by students from different classes, encourages comparison of strategies, and encourages them to reflect on mathematical concepts and methodologies. Finally, after several years of implementation, the community of teachers has generated ideas that allow improvements to the games for the next year's tournaments.

Another important characteristic of interclass tournaments is synchrony. Students play interclass tournaments at the same time and with announcements from the organizers that highlight synchrony. Interpersonal synchronization is important for many cooperative tasks. Reference [73] found that synchrony has significant positive social influences, such as a greater sense of similarity and affiliation. An example of the social impact of synchrony is in the evolution of language. Originally, it comes from grooming between peers. Next, it started collective laughter that synchronizes small groups. In a third stage, it started collective singing and dancing. This moved synchronization to a higher level. This new stage increased social cohesion and collaboration [74]. In addition, with the enjoyment triggered by synchronization, we are more willing to change our behavior. This is a great motivator to integrate and feel part of a community, accept feedback, and transform our practices.

We have analyzed our experience of more than a decade with four different types of interclass tournament. They connect mathematics and computational thinking topics with other STEM disciplines. We found that interclass games are feasible to implement in schools. These are tournaments between classes from different schools with topics from various disciplines. In each case, the whole class participated in teams or as a whole, and students learned central themes of each discipline. They also used and practiced some crosscutting concepts, such as data and patterns, and crosscutting skills, such as argumentation, cooperation, and teamwork. Moreover, we found that the tournaments generated improved student motivation and that students not only enjoyed them but learned some basic citizen values and attitudes, such as fair competition with anonymous others and unknown teams.

To what extent do interclass tournaments help develop educational activities that integrate various disciplines? The integration of different disciplines is a great challenge. However, interclass tournaments offer a platform to help spread activities across disciplines. The innovative environment and lively atmosphere created facilitate trial and error. This helps teachers open their class to introduce core concepts from other disciplines. In the four types of tournament shown in this work, there are some integration components. These successful experiences showed us that this mechanism can be a strategy that helps to overcome the barriers to integration. There are 10 difficult barriers to face, described at the beginning, but interclass tournaments seem to be a technique that makes it easier to lift those barriers.

To what extent do interclass tournaments help to innovate educational strategies? We have studied the evolution of four types of online interclass tournament. They represented a unique opportunity to track changes, as they are recorded specifications for the game software used in tournaments. For each tournament, we studied three types of change. First, there are the major misconceptions that teachers spotted. Given the novelty of the contents in tournaments and the integration of disciplines, these were not always the domain of teachers. Thus, teachers were just learning and spotting misconceptions they had never encountered before. This was very clear, for example, in the games about machine learning. Teachers had never taught machine learning before. The same was true of the momentum game, which had a strong component of engineering and reasoning by analogy. This caused changes in the teaching strategies and requirements for upgrades in the games. Second, there were changes to the teaching practices. On the one hand, it was necessary to address misconceptions. On the other hand, there were new concepts. We listed the most significant changes. For example, a new way of thinking in biology: population thinking. Similarly, completely new problems appeared in the word problem game. This was particularly challenging for fractions. Third, we documented changes to games and tournaments. These were translated into specifications for software changes. For example, being able to bet with models in the machine learning game. Other changes were tweaks to physical devices, such as the trigger mechanism to release the spring and thus shoot the ball.

The four examples of online interclass tournaments presented in this paper show evidence that there was a constant process of cultural learning and innovation. Throughout the years, the nature of the games experienced some changes. Most of the feedback came from trial and error with different features, the reactions and performance of the students, and suggestions from teachers.

6. Conclusions

Until now, scaling new educational strategies has been a major challenge and one that remains. In recent decades, progress in mechanisms for educational scaling has been very limited. Although the technological development of the internet and social networks has allowed a much greater dissemination of information, this has not translated into changes in teaching practices. ICT has an enormous potential to improve quality in education, as proposed in the UNESCO's Sustainable Development Goal SDG 4 [75], and to address the challenges of large-scale teacher professional development [76]. Both the coverage and speed of propagation of educational information, new curricula, seminars, webinars, educational websites, etc. have skyrocketed. However, this diffusion does not translate into changes in educational behaviors or educational beliefs [28].

Interclass tournaments encourage a large community of classes, with their teachers and all their students, to interact under four conditions. First, the interaction is synchronous. This means an atmosphere of increased engagement, motivation, effervescence, and cooperation. Second, this environment makes it easier for the organizer to disseminate messages, strategies, and concepts. This synchronous interaction also makes it easy to receive feedback from teachers and students. Third, homophily. Students and teachers of the same grade level interact. They are students with similar interests and learning goals. Their teachers have to focus on teaching the same topics and doing this in practically the same weeks. Fourth, reiteration. Many times in preparatory events, as well as in the tournament, students and teachers from different schools are interacting. These repeated exchanges facilitate the creation of friendships and close and permanent social networks [36].

The combination of these conditions facilitates the spread of ideas, innovation, and change of strategies. This is a mechanism of cultural evolution different from that of standard teacher professional development and lesson study. In our experience, interclass tournaments, are an alternative worth exploring and further developing. They are an alternative mechanism for enhancing and accelerating cultural evolution didactic strategies.

Online interclass tournaments provide social interaction and learning opportunities between different schools. Teachers and coordinators can imitate more successful ideas and strategies. Online interclass tournaments help teachers to modify activities and test variants for improved teaching of core concepts. They are a new type of academic activity, unprecedented before the digital age. They connect entire K12 classrooms through digital communication, allowing for the exchange of ideas and strategies for a deeper integration of core math and science concepts, crosscutting skills, and meaningful learning. These tournaments promote imitation and recombination of didactic strategies. They are feasible to implement in schools and have the potential to improve student preparation for the challenges of a fast-changing and smarter society. Furthermore, in interclass tournaments, all students participate. This characteristic creates an environment fostering interaction between students of different abilities, accelerating students' learning. This environment helps reduce the isolation between teachers from different schools. Now, the teachers are more aware of each other, they communicate and learn from each other.

This work has several limitations. The first limitation is that the number of different tournament types is very low. They are only four. It is necessary to increase this number and verify the replicability of the main findings. However, this will take many years, so it is a great challenge. The second limitation is that each tournament was followed for a few years. In the future it would be important to carry out continuous monitoring of each type of tournament for many more years. A third limitation is in the degree of granularity of the documentation of changes in teaching practices. More granularity requires a more detailed class observation. Thus, observations of the sessions and the corresponding classification of them according to a certain protocol should be included. For this, it would be necessary to video record the sessions. Then, given the large volume of sessions that would be recorded, analysis could be facilitated with automated analysis tools.

For future work in my laboratory, we foresee several lines of work. First, we plan to analyze innovations in educational materials. For example, changes in the nature of digital materials. With AI and natural language processing tools, changes to textbooks and lesson contents and structures can be easily monitored [77]. The conversion of text paragraphs into vectors through vector embedding facilitates the detection of patterns and the formation and evolution of clusters. Second, we plan to study thousands of classes. Machine learning tools make it easy to automate the classification of events according to different classroom observation protocols [78]. This, in turn, makes it possible to detect clusters of lessons and their evolution [79]. Third, an area of great interest is to detect changes in the types of open-ended questions posed by teachers and the evolution of the corresponding students' answers. Machine learning tools and large language models make these analyses possible [80]. Fourth, another area of great interest is student teamwork. Machine learning makes it possible to automate part of the analysis. We plan to start monitoring changes in team strategies and their innovations over the years. We already have some promising preliminary results [81]. Fifth, we are planning to study changes in students' attitudes and socio-emotional behaviors. For example, interpersonal behaviors, intraclass versus interclasses collaboration, and the structure and cohesion of the different social networks that naturally emerge in the classrooms.

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Informed Consent Statement: Student consent was waived due to authorization from teachers. Given that there are no patients but only students in a normal session in their schools, within school hours, and using a platform that records their responses anonymously, the teachers authorized the use of anonymized information.

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education sciences

Article

Game On, Reflection On: Reflection Diaries as a Tool for Promoting Reflection Skills in Geography Lessons

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Abstract: In this study, a diary was developed and used by students to reflect on digital games in geography lessons. The students' reflection results, through the use of the diary, were compared with reflections without instructional guidance. These results show a significant improvement in reflection through the use of the reflection diary compared to a previous study. Through the combination of lessons, play phases, and the reflection diary, a learning arrangement that enables in-depth reflections at different levels of reflection was created. The medium plays a decisive role by taking the pupils out of their role as players and enabling a critical distance to the game. With the help of the reflection diary, students should be able to better reflect on the game. The reflection diary is integrated into the lessons. It also shows that subject-specific lessons are indispensable for reflecting on the gaming experience in order to counteract subject-specific misconceptions.

Keywords: digital game-based learning; urban planning game; reflection competence; reflection diary; geography lessons

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1. Introduction

Digital games are becoming increasingly important in the classroom [1] as they can be used to teach content, media competence, and specific knowledge in subject lessons, in an interactive and engaging way. They combine fun and education, which makes learning more interesting and motivating for students [1]. In today's world, children and young people are growing up with new media and social networks. Therefore, it is important to build on students' everyday experiences [2]. According to Prenksy [3], students have a positive attitude towards video and computer games. Therefore, educational media that are of particular interest to students should be used.

Studies have shown that the number of video game players worldwide will increase to three billion by 2023 [4–6]. Other studies show that 90% of young people in Germany between the ages of 10 and 18 play digital games for up to two hours a day [4–6]. In summary, it can be said that millions of people play digital games as a leisure activity but may not be aware of the learning processes that are triggered by the games [7].

Digital games can be used as a learning medium in the classroom for different subjects and age groups [8]. According to a systematic review and meta-analysis by Clark and Tanner-Smith [9], digital games offer the possibility of using simulations and virtual experiments to facilitate the understanding of complex phenomena in the natural sciences, for example. Similarly, in his collection of essays, Gee [10] emphasizes the positive impact of digital games on students' learning and literacy. Reinders [8], based on various studies, emphasizes that in the field of language learning, there are positive effects of games in terms of motivation, willingness to communicate, language socialization, and other language learning processes.

In addition, digital games in the classroom can also help to develop students' social and cognitive skills. Squire [11] argues that many games require teamwork, critical thinking, problem solving, and decision-making. Playing games together and interacting with other students also promotes social skills such as communication, cooperation, and conflict resolution [12]. Learning through games offers a variety of benefits for all age groups. Games stimulate the interest of learners and increase their willingness to actively engage with the subject matter. The playful component involves learners in the game process [7].

By actively participating in the game, they can apply their knowledge and skills, solve problems, make decisions, and experience consequences [13]. This promotes deeper understanding and better retention of learning. Furthermore, games provide a safe space where learners can make mistakes and learn from them without negative consequences in real life [14]. By having the opportunity to try different approaches and experience consequences, learners can improve their decision-making and develop new strategies [2]. However, it is important to distinguish between serious games and commercial games. There is no single definition of serious games, but they can be distinguished from commercial games. Abt [15] makes the distinction between commercial games clearer by explicitly emphasizing that serious games have an educational goal, although commercial games have some advantages. Commercial games can increase motivation and engagement in the classroom [16]. In addition, many games require critical thinking and problem solving skills to overcome challenges in the game. These skills can be transferred to other areas of learning [17]. The games also provide an immersive experience that can enhance the understanding of content. Students learn through hands-on experience [16]. The culture of error and perseverance is also repeatedly emphasized. Games encourage students to learn from mistakes and develop perseverance to overcome difficult challenges. These skills and abilities are also relevant in a school context [2]. In addition, commercial games address complex systemic geographic issues such as climate change, migration, urban development, and resource use [18]. The complexity arises from the many controllable variables, the different actors, the required actions, and the difficulty of predicting the subsequent effects [19]. Due to the high complexity of commercial games, students engage with the game system and are motivated to learn its mechanics [20].

It should be noted that commercial games have great potential as educational media and are often superior to serious games in terms of the complexity, design, and treatment of current social issues, some of which allow very limited actions and whose design is often less appealing [21]. This paper therefore refers to commercial games used as learning media in geography classrooms.

Reflecting on the game experience and content after playing the game in class is very important to ensure that students do not consolidate false or oversimplified contexts and that the potential described above can be realized [22]. In addition, reflection on the medium can also contribute to the promotion of media literacy. Media literacy refers to the ability to use media, to understand and critically evaluate different aspects of media and media content, and to communicate in different contexts [23]. Reflecting on actions is also essential in gaming. Action skills can be derived and adapted to the real world. Game decisions and actions can be used to gain knowledge about oneself and to highlight one's own values (personality development) [22].

A study by Baßeng and Budke [22] shows that students who played a digital city-building game (PocketCity) in class, and were then asked to reflect on it without being instructed to do so in class, primarily reflected on the game logic and game mechanisms. By trying out different actions, they were able to see immediate effects and thus make direct connections. However, self-reflection was limited. Students also have great difficulty comparing the reality of the game with the reality outside the game. There are also hardly any approaches to reflect on the medium. Lux and Budke [24] came to similar conclusions in their study. They investigated the extent to which young players can reflect on social issues in digital games in an informal context.

In the present study (fallow-on study) we build on the results presented on students' reflection of digital games without instructional guidance [22] by repeating the study and this time using a reflection diary as a didactic tool to support game reflection accompanying games in geography classes. The reflection diary is based on the structure of a learning diary. This means that students are asked reflection questions that they have to answer in writing after the game phases. The play phase is when the students play the game on their own.

In an intervention study in Germany with 29 tenth grade students (age 15–16) who played the digital city-building game PocketCity in geography class, we investigated the following research question:

To what extent can students' reflection skills on digital games be improved by using a reflection diary, parallel to playing the game, compared to reflection without instructional guidance [22]?

In the following chapters, the theoretical background, methodology, and results of the study are presented and discussed.

2. Theoretical Basics

2.1. Learning Potential of Digital Games and Game-Based Learning

Digital games offer great potential for learning in the classroom. They can motivate students in a variety of ways, expand their knowledge, and improve their cognitive skills [8]. By properly embedding digital games or game elements in the classroom (game-based learning), subject-specific learning can be deepened.

It is difficult to find a universal definition of game-based learning [25]. Most definitions or concepts emphasize that games are used to acquire knowledge, or for educational purposes [26]. Game-based learning offers great potential for making classroom learning effective and motivating. By using playful elements, students are actively involved in the learning process and can expand their knowledge and skills in a fun and entertaining way [27]. Players also have to act according to certain rules and solve tasks in order to be successful in the game. Digital games create new spaces for action and experience in which students can learn individually and at their own pace [28]. Research has shown that game-based learning increases student engagement and motivation. The playful nature of the learning activities can motivate learners to engage more deeply with the subject matter. For example, a study by Clark et al. [9] found that students who used game-based learning in math classrooms had higher levels of intrinsic motivation and a better understanding of math concepts than students who were not exposed to game-based learning.

In addition, game-based learning promotes the development of students' problem-solving and critical thinking skills [2]. Playful elements, such as challenges, puzzles, and decisions, in games require learners to analyze complex problems and develop solution strategies; for an overview, see [29].

Another advantage of game-based learning is the promotion of cooperation and social learning. Many games provide opportunities for students to collaborate and work together [12]. This not only strengthens their teamwork skills but also promotes knowledge sharing, collaboration, communication, and the development of social skills [30]. Incorporating playful elements such as scoring systems, levels, and rewards makes learning activities interesting and appealing [31]. A study by Hamari et al. [32] found that the playful design of educational applications can increase students' intrinsic motivation. Digital games also allow learners to be active and apply their knowledge, with creative use contributing to media literacy and digital maturity [33]. They often offer complex scenarios and problem-solving tasks that require students to apply their knowledge in practice. This promotes critical thinking (consider different perspectives), decision-making, and problem-solving skills [8,34]. A study by Clark et al. [9] found that students who used digital games in class had higher levels of active participation and interaction than students who did not play digital games. Digital games can be tailored to individual learning needs. In addition, they can offer different levels of difficulty, customization options, and feedback mechanisms to meet the diverse needs of learners. A study by Hwang et al. [35] showed that adaptive digital games can improve student learning outcomes. Digital games can be used to convey complex content in a clear and engaging way. Simulations and interactive experiences can make abstract concepts more tangible, allowing students to acquire skills and reflect on and question their own choices; all of this can be tested in a safe space [14]. A meta-analysis by Wouters et al. [36], which examined the learning effectiveness of serious games compared to conventional teaching methods, concluded that digital games have a positive effect on knowledge acquisition and the ability to apply knowledge. The players achieved a particularly high learning effect when the game was complemented by other teaching methods [36]. A meta-analysis by Vogel et al. [37] also concluded that students who learned with games and simulations achieved significantly better results and more positive attitudes toward learning than students who were taught traditionally.

Digital games are used in the classroom to stimulate motivational processes, arouse interest in certain topics, use interactive learning methods, and present phenomena in a realistic way [12,38–42]. Petko [12] also mentions the high motivational potential of digital games in the classroom, especially for students who otherwise find it difficult to get excited about learning content or who have low attention/concentration spans. Commercial digital games often model geographic issues such as urban development, climate change, migration, and sustainable resource use [43]. Students themselves also recognize geographic themes in commercial games, such as natural disasters, interacting with nature, or dealing with wars and crises [44]. In one study, Jolly and Budke [45] investigated whether the commercial digital simulation game "Cities: Skylines" allows players to simulate sustainable urban development. The scientific criteria and indicators of sustainable urban development in the game are cited as key findings. The game "Cities: Skylines" offers the opportunity to gain deep insights into sustainable urban planning [45]. Students can learn and experience the connection between urban geography and sustainable cities in practice, which means that the game has great potential for geography education [45]. Morwaski and Wolff-Seidel [44] summarize that video games are a valuable tool for geography education, but it is important to carefully analyze the limitations and opportunities, as well as critically evaluate the content, before using the game in the classroom. Games can be used for more than just creating your own learning products or completing assignments. It is also possible to consider games as objects of study and to analyze and discuss their content and forms of presentation. Digital games can be used as an object of reflection in the classroom [46]. However, most of the existing studies investigate learning gains and motivation through digital games. Targeted studies on the reflection of digital games in the classroom are not yet available.

In addition, few didactic approaches are known to support students' ability to reflect on the content of digital games. In this context, we developed and tested the reflection diary.

2.2. From Learning Diary to Reflection Diary

First of all, the term reflection needs to be looked at more closely. The term reflection can be divided into reflection on content and the learning experience, according to Dewey [47], as well as reflection on one's own actions and the development of alternative courses of action, according to Schön [48,49]. Furthermore, a distinction is made between the concepts of reflection and reflexivity [50]. The difference is that reflection takes place at the level of the object, while reflexivity is based on the level of one's own perspective and self-reflection. This means that one considers one's own thoughts and actions in relation to an object by changing one's perspective [50]. The model in Figure 1 is used to reflect on digital games in the classroom [24] and has four different levels: reflection of the system in the context of the game, reflection of the system in the context of the world outside the game, self-reflection, and reflection of the medium (digital game). Reflection of the system in the context of the game, as well as at the reflection in the context of the world outside the game, is important because reflection helps to distinguish the game logic from reality outside the game and to recognize the successes and limitations of the game in modeling real-life situations ([24]; level 2). The reflection of the medium is also highly relevant. This concept of reflection is often found in connection with media literacy [24], which includes the critical handling and reflection of media [51]. Students should recognize the potentials and limitations of the medium of digital games in order to learn how to use this medium critically and competently ([24]; level 4). These reflections can relate either to the medium of digital games in general or to digital games as an educational medium. Players' self-reflection is also important in order to understand their role in the game and in reality, as well as their actions, attitudes, and values ([24]; level 3).

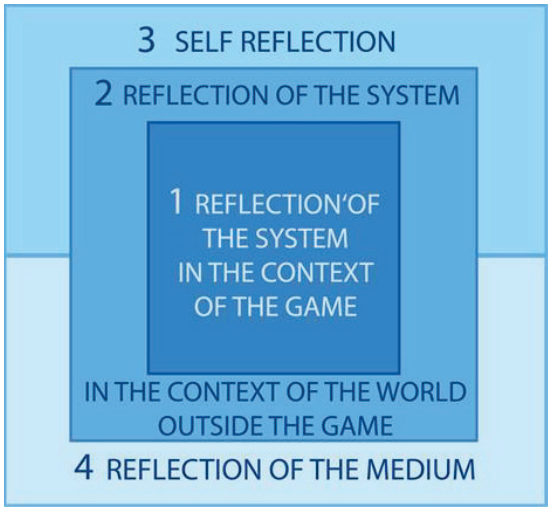

Figure 1. Model of the levels of reflection on digital games [24].

Since the previous study [22] had shown that students reflect on digital games without guidance in the classroom, primarily at the level of the system at the game level (level 1, Figure 1), an intervention was created to guide reflection at all levels of the model. Based on this model, reflection diary questions were created for students to answer after the game phases. The design principles of learning diaries were used in the creation process.

Learning diaries are understood as "continuous, written and reflective engagement" [52] with learning content or the learning process [53,54]. The goal is to encourage students to engage with their own learning process and to deepen their understanding of learning content, as well as to implement strategic learning [55].

Learning diaries enable students to reflect on their learning processes, deepen their understanding, and consolidate their knowledge. This approach can promote self-directed learning, metacognitive skills [56,57], and the development of writing skills.

A study by Guce [58] investigated the use of reflection journals in mathematics classrooms. The results of the study showed that reflection journals had several positive effects. First, they enabled students to construct meaning and express their personal views and ideas. Second, the journals fostered a close relationship between teachers and students. In addition, the use of prompts in the journals improved students' understanding by connecting mathematics to real-world facts, and the journals helped students to make connections between ideas by using their prior knowledge and experiences. Finally, the journals helped students to develop self-confidence.

Another study [59] examined the use of learning journals in higher education and found that reflection through journal writing helped students understand their learning processes and recognize their thinking patterns. This led to improved metacognitive skills and better self-regulation of learning.

In Hatton and Smith's [60] study, using learning diaries in a medical education program, it was found that by reflecting in their learning diaries, students developed a deeper understanding of the topics covered and improved their critical thinking skills.

Reflection in journals can also help students to better organize their knowledge and make connections between different learning content. A study by Boud [61] investigated the use of learning diaries in university education and found that reflection in diaries helped students to structure their knowledge and improve their learning outcomes. The use of learning diaries in the classroom is varied [62,63]. Learning diaries are also often used in adult education, e.g., for student teachers during their internship. The focus is often on the critical reflection of one's own practice [64]. Hartung-Beck and Schlag [62] emphasize that successful and self-regulated reflection requires targeted instruction and support from faculty staff. Hartung-Beck and Schlag [62] summarize what is needed to create an effective learning diary.

They cite guiding questions or prompts (cues to activate knowledge) as conducive to learning [52,65].

In an empirical article by Hartung-Beck and Schlag [62], they point out that the length of the learning diary and the frequency (how often the learning diary is used) [66] also influence the quality of the learners' reflections. They also see a connection between these two factors and acceptance and motivation to write a learning diary. They note that learner acceptance can be influenced by providing information about goals and benefits.

They see the detailed feedback as another important point. The feedback was found to be particularly helpful, especially as a supplement to the prompts. Based on the evaluations, Roelle et al. [67] were able to show that feedback from instructors, in addition to guiding questions/prompts, leads to positive learning experiences, especially for learners with a low level of expertise. Strauch et al. [66] emphasize that working with the learning diary should be integrated into the entire learning process. Fixed processing times need to be respected and planned [66].

The above-mentioned design approaches for learning diaries were followed and adapted to a diary for reflection on digital games. The reflection questions were developed on the basis of a model of levels of reflection on digital games ([24]; see Figure 1). The questions were answered partly in writing and partly orally by the students (see Figure 2).

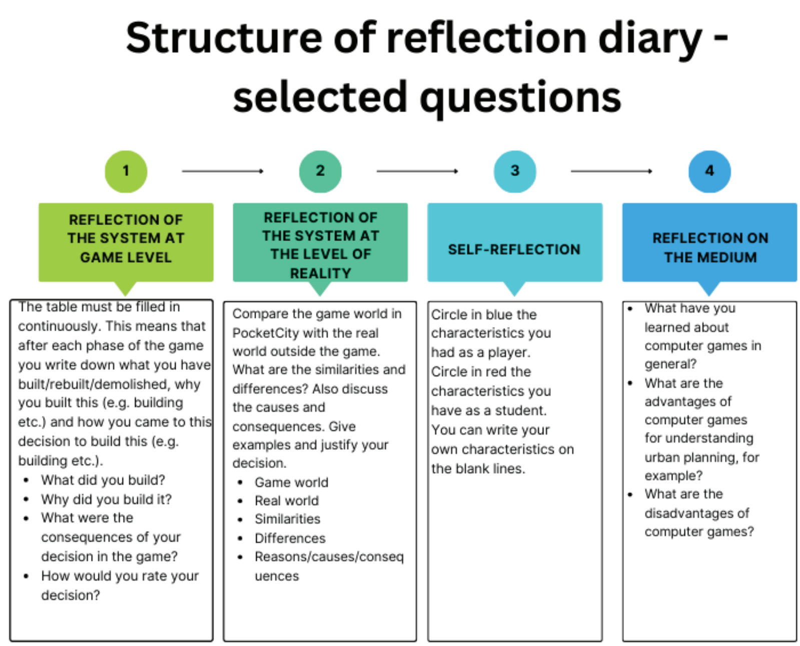

Figure 2. Structure of the reflection diary—selected questions (own illustration).

The focus of the reflection diary is to reflect on the game experiences on different levels (see Figure 1), and, for each level, questions were formulated, some of which are shown as examples in Figure 2.

3. Materials and Methods

This chapter presents and justifies the methods used in this research.

3.1. Sample and Selection of the Game

A total of 29 students, 16 female and 13 male, participated in this study. All 29 students attend the tenth grade of a public secondary school in North Rhine-Westphalia and form a natural class (a class that was not put together specifically for the study). There is one transfer student in this class who is learning German as a second language. The students are between 15 and 16 years old. In order to find out about their previous experience with digital games, we used a pre-test in which we asked about their previous knowledge and digital equipment. Based on the pre-test, it can be seen that the students in our study have similar characteristics to the young people in the JIM study (JIM = Young, Information, Media) (2021) [68] and the study by Baßeng and Budke (2023) [22] in terms of socio-demographics, device equipment, and media activities in their free time.

In addition, it can be noted that almost all students, with one exception, had already gained experience with digital games. There were no gender differences. This means that almost all students had the same prior knowledge of digital games.

The aim of the sample selection was to ensure that the topic of the research project (urban development) fit both the lesson plan and the curriculum of the ninth and tenth grade. In grades 7–10, at secondary schools in North Rhine-Westphalia, the urban theme is very relevant for geography classes (see the core curriculum for secondary schools in North Rhine-Westphalia). Topics such as mixing and segregating functions, basic functions of existence within the city, and the structure of a city are mentioned. In geography classes, students should acquire various skills, such as the analysis of human–environment relationships (SK 6), the recognition of possible conflicts or future situations through simulation games (here: digital games, MK 8), and the ability to plan, implement, and evaluate a subject-related project, e.g., the creation of their own city (HK 6) [69].

The students played the commercial city-building game "PocketCity" (developed by Codebrew Games) for 90 min (two lessons) per week over a period of seven weeks and completed the reflection diary.

The decision to use PocketCity was based on the fact that it is easy to understand and less complex than other city-building games such as Civilization VI or Topico [19]. It was considered appropriate for this age group and this type of school. Simplifying the content of the game was important as it was intended to be used in a school context. The city-building game is available as an app and can be easily installed on tablets and smartphones.

"PocketCity" is particularly suitable for introducing students to the genre of economic and urban planning simulations. It takes into account the basic mechanisms and functions of a city, such as living, working, recreation, etc. Although the game has a simple structure and is easy to understand, it offers a sophisticated depth of play that is particularly suitable for geography classes.

In PocketCity, players must build and expand a city while maintaining a good balance between residential areas, commercial and industrial zones, and recreational facilities. The infrastructure, such as road connections and water and electricity supplies, must also be taken into account. Players take on the role of the mayor and receive information about missing buildings or requests from citizens via comment functions. If the players follow these instructions and the city grows in size and population, they advance to the next level, where "special" buildings such as a zoo, castle, or Ferris wheel are unlocked [70].

3.2. Research Design

In order to obtain high-quality results, a combination of quantitative (pre-test) and qualitative (reflection diary) survey methods was used.

In the pre-test, the focus was on collecting information on gaming experience, home equipment, and students' prior knowledge of the functions of a city/urban planning. Media-related questions are based on the JIM study (2021) [68]. The reason for basing the questions on the JIM study is to use a validated survey tool, to form validated categories, and to be able to classify the sample in terms of representativeness [22]. Furthermore, the learning groups from the first study can be compared with each other as the procedure is the same [22]. As described above, the reflection diary was created based on the principles of learning diaries. Questions from the pre-test were also included in order to establish comparability with regard to the knowledge acquired in relation to the functions of the city/urban planning. In addition, tasks were set that had to be completed repeatedly throughout the entire game phase (see Figure 2). This was carried out to assess the students' ability to reflect on the game and their knowledge of urban functions and urban planning.

The teacher was able to view the reflection diaries, but there was no sharing among the students. The oral responses, which were also included in the reflection diary, were recorded using the voice memo function of the iPad. The survey methods were the same as in the first study in order to best compare the results. The survey method using the voice memo function also proved to be very advantageous [22]. On the one hand, the students can explain their answers in detail, and, on the other hand, the interviewer cannot influence the answers, which means there is an advantage in that the answers have a low social desirability. The questionnaire (pre-test) and the reflection diary were completed voluntarily by the students. Therefore, the response rate was 100%. Parents and pupils were given comprehensive information about the study. A declaration of consent was also obtained from the parents. The first author was also the teacher who conducted the study and therefore had knowledge of the students' strengths and weaknesses from the classroom.

Figure 3 illustrates the chronological and methodological approach.

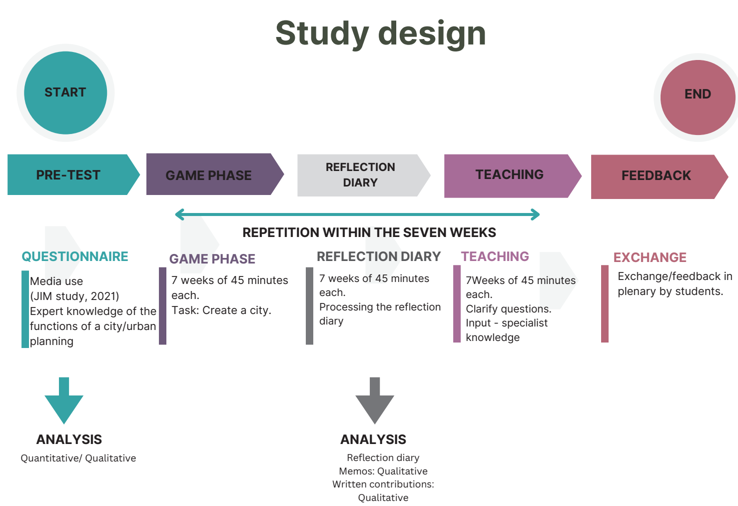

Figure 3. Study design (own illustration).

First, the students completed the questionnaire (pre-test) on media use/equipment and subject knowledge. This was followed by a 45 min game phase. The students were asked to build a city using the urban planning game PocketCity. This was followed by a 45 min teaching phase. The lessons were designed to clarify the students' questions/uncertainties and thus generate knowledge growth. The students' questions allowed for a more in-depth discussion of certain topics, such as the separation and mixing of functions. The teaching phase was also used to fill in the reflection journal in detail. The alternating play and teaching phases were played/taught over seven weeks, each lasting 45 min. At the end, the students reflected on the study project. There was a final exchange in plenary.

3.3. Evaluation

The data from the pretest were statistically analyzed descriptively. The pretest was analyzed using the Excel spreadsheet program. The voice memos from the reflection diary were transcribed. The transcripts and the written contributions from the reflection diary were then analyzed using MAXQDA (software version 2022 for qualitative data analysis) according to Mayring's (2010) [71] qualitative content analysis. First, deductive categories related to the model were formed (see Figure 1). The decision to conduct the analysis deductively is due to the fact that the approach is theory-based and because the analysis from the first study was also deductive. Further inductive subcategories were created based on the empirical data so that no important information was lost. The texts were then read again for relevant information and the individual and important information was then assigned to the categories (coding) (see Figure 4). Finally, all the collected information was summarized.

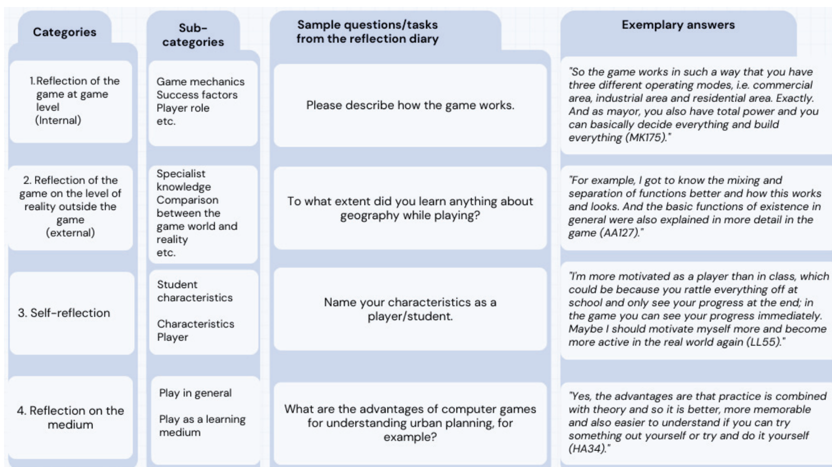

Figure 4. Presentation of the categories/questions of the reflection diary and sample answers from the students (own illustration).

3.4. Reflection on Methods

A possible weakness of the study is that the written answers to the questions in the reflection diary were given in individual work, and it was not possible to ask the students any questions about ambiguities. Nevertheless, it can be stated that the choice of methods led to valuable information that served to answer the research question. The decision to record some questions in the reflection diary as audio recordings is due to the fact that most students find it easier to describe processes verbally. In addition, a variety of methods (written contributions and oral contributions) are of great importance [72,73] in order to maintain motivation to complete the reflection diary conscientiously. The small sample size (N = 29) should also be mentioned, as it is not possible to draw any general conclusions from this. Accordingly, this is an exploratory study. It should also be noted that the study only took place at one type of school in Germany—Realschule. It cannot be ruled out that different results were obtained at other types of school. There is also a weakness in terms of validity, as the variables are not directly observable or measurable [74], but an attempt was made to achieve the highest possible validity by formulating the questions in the reflection diary using the model (see Figure 1). A certain blindness to already defined analysis categories can also arise, so that not all results fit into the defined categories.

However, the deductive approach was deliberately chosen because, as already described above, the evaluation was consistent with the first study [22], and the main categories were created on the basis of the model (see Figure 1). These categories proved to be very useful for analyzing the results, and it was possible to draw a precise picture of the different levels of reflection.

4. Results

The results of the study are presented below, structured according to the four levels of the model for reflecting on digital games (see Figure 1).

4.1. Reflection

Below is a reflection of the system in the context of the game (model level 1).

Questions on reflecting on the game system were often answered in great detail by the test subjects. It can be seen that the test subjects were largely able to understand the content and the contexts and had thus internalized the game logic.

The students were usually able to name the factors for success in the game and the role they played.

> *"You take on the role of the mayor in the game"*. (AA127)

In response to the question regarding the central game mechanics "Please describe how the game works!", almost all students mentioned the construction of the various zones—industrial, commercial and residential areas—as well as the attention paid to the satisfaction of the population. This was followed by "money" and "completing tasks (quests)" as further success factors.

The students correctly highlighted the success factors and thus also recognized connections. The monetary resource was important in the game in order to acquire more territory and expand the city. In addition, expanding the city and successfully completing the quests takes you to the next level, which, in turn, unlocks more buildings. The students also mentioned the satisfaction of the population, which is dependent on other factors: for example, the higher the satisfaction, the more population in the city. The students had to respond to the wishes of the population and, for example, reduce taxes in order to increase the population's satisfaction.

> *"You have to earn money, and to earn money you need residents in the city. And these residents have to work, but at the same time be satisfied with their lives so that they leave money for you. And you get money, for example, by building this leisure facility or raising taxes, which in turn reduces the satisfaction of the residents"*. (LA109)

> *"You should always build the city bigger and construct more important buildings that meet the needs of the citizens. You should also always make sure that there are enough citizens in the city, i.e., satisfy leisure activities and needs. Updates for zones and improvements for zones should be used. You should always make sure that demand and supply are roughly equal"*. (FI274)

In the game, the students find themselves in situations in which decisions have to be made between several conflicting goals. Some learners realize that they cannot consider all goals or achieve all goals at the same time (see quote from LA109).

The second example shows that the learner has developed a strategy to deal with the different demands. It is clear that the learner considers the balance between the different parameters to be very important and so explains his next steps.

In general, the two examples show that the students demonstrate a systemic way of thinking as they recognize causal relationships in the game mechanics, e.g., between the number of inhabitants and population satisfaction/increase/decrease in taxes, but also between "earning money" and "buying territory" as well as fulfilling quests, and they derive action decisions from this.

The examples also show that students see the interaction between the population and income/taxes. If one element changes, it affects the other. Almost all of the students' answers are very detailed. Based on the quality and depth of the answers, it can be said that the students largely understood the logic of the game. They also named their strategies (What needs to be done now to progress in the future?) in the game to make it successful.

> *"You start building residential areas. You get taxes. With the taxes you can build more roads to build business parks and industrial estates so that people have places to work. And then they start working in the jobs and then you get more money. You can then use the money to buy more land and expand your city. You always need enough power plants and resources. If there is a certain capacity that the power stations and waterworks can accommodate, that means, for example, a small power station for 50 houses and then you build them and once you have built them, you can connect everything. So that runs via the roads, to the houses and to the buildings, to the leisure activities or power plants/steel plants"*. (YZ9)

The example shows that the student is able to recognize the dependencies of different (success) factors. He realizes that power plants can only supply a certain number of houses and that there must be several power plants to supply an entire city with electricity.

Based on his decisions and feedback, the student realizes that not only one power plant is sufficient for his city but that several are needed. He has to solve a complex problem by making repeated decisions. The game reacts to the player's decisions, for example, with feedback functions. The students then have to react to the game's reaction. Students understand that they cannot take all factors into account satisfactorily and develop a strategic approach.

4.2. Reflection of the System in the Context of the World Outside the Game (Model Level 2)

At this level, a comparison between the game (PocketCity) and the real world outside the game is made in order to identify similar contexts and to recognize the limitations of the game.

In the task of comparing the game world with the real world, all students gave detailed answers in their reflection diary.

They often made visual comparisons. For example, they wrote that the "red cross" symbol in the game is typical of a hospital. The symbol is used in both the game world and the real world to identify a hospital.

The students mentioned other differences between the game world and the real world that also helped them to identify the limitations of the game. For example, some students mentioned the limited infrastructure expansion. Students were only able to build the buildings specified in the game. For example, only one port could be built. In the real world, unlike the game world, you can build multiple ports. Also, you do not have to wait for a higher level to build buildings.

Some students noted that the options for action in the game were limited. The game provides the options, and the players must build a city with those options.

Many students realized that some options in the game were not comparable to the real world. For example, farms could only be built on a certain type of land.

Many students also questioned the limited number of stops (game elements) they could build and felt limited in their actions as a result.

> *"There are more stops in real life—in the game you can only build stations"*. (NA39)

Only one student explicitly mentioned the limitations in reality (cf. LO88). Different options for action in the real world are also influenced by different regulations. An example of this is the construction of buildings, which must comply with various regulations and standards. There are also other constraints in reality, such as existing laws and socio-political groups. The student only mentions the laws that need to be taken into account but does not go into further detail.

> *"I've learned about computer games in general that everything that goes through an app doesn't always correspond exactly to reality. By reality I mean, for example, that you have to obey laws in the city, but you don't have to do that in the game online."*. (see LO88)

There is also an option to turn off the forces of nature in the game, such as tornadoes or volcanic eruptions. All subjects were aware that this option was only available within the game and not outside the game. All students found this option unrealistic.

Many students also critically questioned the high level of power of the player in the game, who as the mayor decides on urban planning, and classified it as unrealistic in the context of urban planning.

> *"In the game, you are the mayor. You have to build and decide everything. You have the ultimate power. This role is very unrealistic, because in reality the mayor only has the right to co-decide at best. In reality, the mayor does not make as many decisions as in the game. In the game, you have ultimate control, you can decide everything and even change the landscape. This is very unrealistic"*. (FI274)

This example makes it clear that the respondent considers the high position of power of the player who makes the decisions as mayor to be illogical. The choices of words "ultimate control" and "this role is very unrealistic (...)" make it clear that the learner thinks that this position of power is only possible in the game. The learner compares the mayor's position of power in the game to the real world and can therefore clearly identify the misrepresentation of the position of power in relation to the real world. By comparing the game with the real world, the learner can more precisely name the flawed structures in the game; as a justification, he names the political structures, i.e., the structure of the political–democratic system.

4.3. Self-Reflection (Model Level 3)

On the level of self-reflection, we were able to show that all students were able to name their characteristics as a player and as a student in great detail. They were therefore able to differentiate between these two roles.

All students described themselves as motivated and interested when they were in the player role: *"Ambitious, motivated, interested (cf.* e.g., *JN106)"*.

The following example shows a student reflecting on her behavior in the game. She analyzes her playing style and derives personal characteristics.

> *"As a player, I'm more motivated and ready to develop everything in the game, it's very varied and fun. You have to be organized to coordinate everything in the game. The game shows me that I can keep calm when I need to"*. (TO467)

Another student even derived a future career aspiration from the gaming experience. "All in all, games are more fun and more interesting. They are captivating and educational at the same time. I could imagine a career in IT because I love digital things (MK175)." Another student also draws conclusions from the gaming experience and links them to his behavior in everyday life: "It (the game) showed me that I should pay more attention to things where I can help shape things (LN340).

Another student compares her self-observations during the game and at school, recognizes some similar characteristics in herself, and analyses her different feelings when learning with digital games and in "normal" lessons. She draws conclusions as to which learning settings would be suitable for her.

> *"There aren't really any differences between my characteristics in the game world and my characteristics in the real world. In both, I'm motivated, I care about others and I'm interested. However, I notice that I have a lot more fun when I'm playing than in class. I always look forward to lessons because the game allows you to combine creativity and strategy with learning. You learn while you play the game and that's something different. For my everyday life as a student, I notice that I have more fun learning in a playful and virtual way"*. (AN311)

Individual students describe how the quick and visible success in the game contributes to a high level of motivation to learn as well as the powerful player role they take on in the game. *"I am motivated because you can see clear learning successes and my participation in lessons, you have a clear connection to life and you feel in a position of power" (BA11).*

In general, learners have found access to reflect on their learning experiences and preferences through their gaming experiences.

4.4. Reflection of the Medium (Model Level 4)

In response to the question "What benefits did playing digital games in class have for you as a student?", all the students said that the game made it easier to understand the topics of urban planning and the functions of a city. They also mentioned the fun of learning and the change from other teaching methods. They also praised the opportunities to try things out and the visual representation of the topics (urban planning and basic functions of existence) (cf. YZ9).

> *"For me as a student, it's cool to play games in class, because it's a better way to teach things and you can process things better by playing. You remember it better because you're also playing it yourself and trying it out and you can see what's possible and what's not possible. You can just let your thoughts run free and try things out so that you can ask yourself questions and answer them yourself"*. (YZ9)

> *"Yes, I found it very helpful because sometimes you were at a point where you didn't understand why people were moving away from the city and why you weren't getting any more money. And then in class, when you discussed, for example, the basic functions of existence and so on and then you realized, oh, I'm not fulfilling one of them, then you changed it and then suddenly people came back and it helped you a lot. Or also how to really separate and mix functions properly once you had the money to implement it"*. (NA39)

The second quote shows that the student praises the combination of learning and play in the lesson. He was able to gain expertise through the lesson and tried to use this knowledge in the game. The student recognized that individual factors depend on others. Furthermore, the student mentions the possibility to try things out as an important advantage of digital games. For the learner, the self-control and self-efficacy experienced while playing the game is crucial for a positive learning experience.

Compared to school lessons, the game offers a space without grading performance. Students can perform actions in the game that they can correct again. Subjects described this option as particularly helpful for learning.

> *"The advantages of computer games, for example to better understand urban planning, are that they improve me when I make mistakes and give me tips on how I can do better next time so that I don't repeat these mistakes"*. (LN340)

> *"In the game world, you learn while playing and can memorize things much better. You also have more fun and no stress when learning. In the real world you have more pressure, maybe you have to choose different strategies"*. (FI88)

Several learners mentioned the high pressure to perform in class as opposed to playing the game. The digital game PocketCity is perceived as a counterbalance to "normal" lessons. In relation to this, one student (FI88) mentions that a different strategy should be chosen; it can be assumed that he is referring to the learning methods in lessons and that the regular uses of digital games in lessons can create a balance between grading and sanction-free spaces.

All students were able to name general limitations of the medium of digital games outside of the classroom context. All students stated that they felt their actions were impaired by the different levels. The students were only able to "unlock" certain leisure attractions (e.g., amusement park and Ferris wheel) or buildings (e.g., schools and town hall) at higher levels. This meant that the students were not in a position to consider all the basic functions of existence within a city right from the start (cf. BA11).

> *"I felt restricted when I wanted to build things like a harbor but couldn't because of my low level"*. (BA11)

> *"If you didn't have enough money, you couldn't fulfill any tasks. For example, building a school so that the children could go to school and continue their education. You couldn't do that, for example, because you didn't have enough money. Or if you needed more security, you couldn't directly build more fire departments and police stations because you didn't have enough money and weren't at the level where you could get a fire department, for example"*. (LL55)

The examples show that the students were able to perceive the different obstacles in the game they played but without drawing conclusions for the medium of digital games in general.

In addition, the students were limited in their choices because some actions were dependent on higher levels. Students were not able to choose between separating and mixing functions at the beginning of the game.

In general, the players felt restricted at all times due to a small amount of money, small areas, and the dependence on the level, as they were unable to directly implement content from the lessons.

Topics such as separation/mixing of functions and the basic functions of existence were covered in class, but these could only be considered gradually during the game, which the players found annoying. They also found it a hindrance that all locations had to be connected to each other: *"Roads must always be connected—even to the beach (JN106)"*, and buildings could not be "rotated": *"Houses cannot be rotated, can only be built in one direction (ND75)"*. This made the buildings very static and not adaptable to the environment. The students thus also experienced the limits of the game played but without thinking about why these limits exist. For example, none of the learners pointed out that digital games are created by game developers and are used for entertainment. For a game to be playable at all, the content must be reduced in its complexity, and the students did not mention this point either.

It is particularly noteworthy that all students were only able to name the general advantages and disadvantages of digital games to a limited extent. This example shows that the students summarize general advantages such as being able to express creativity within a game.

> *"Computer games have taught me that you can simply be creative in the digital world if you can't live it out in the real world. You can also develop yourself through computer games, you can develop new interests, you can learn things, you can be more interested in things"*. (YZ9)

The advantages (as a learning medium), as already described above, relate to trial and error, the sanction-free space, and the visual representation of urban planning/basic functions of existence.

All students mention the advantage of lessons and play phases, as well as the varied methodical geography lessons.

The disadvantages, which the students reflect on very well, are also very well founded. The students can recognize the reduced representation of urban development measures.

The following examples illustrate the statement that the students have understood the limits of the medium very well. They are aware that digital games do not reflect reality and that complex structures are presented in a simplified way. In this context, one student (AA127) also mentions the disadvantage of incorrect knowledge acquisition and reflects on the importance of digital games as a learning medium.

> *"Disadvantages (of digital games) would be that not everything is like in real life and you could acquire the wrong knowledge"*. (AA127)

In summary, the students reflected very intensively on the specific game. The learners reflected on the game in great detail with regard to its suitability as a learning and teaching medium, but reflection, in general, was only rudimentary.

5. Discussion

This study investigated the extent to which students' reflection skills in relation to digital games were improved by using a reflection diary in parallel with playing the game compared to reflection without instruction [22].

A key finding of our study is that students engaged in significantly more reflection using the reflection diary than in the first study by Baßeng and Budke [22] in which students were not instructed to reflect. This is because, as Lux and Budke [24] point out, reflection must be encouraged from the outside (e.g., by teachers) in order to address the levels of reflection that are central to deeper understanding (see Figure 1). The promotion of media literacy through the use of the reflection diary after the game phases should also be emphasized. On the one hand, media literacy refers to an individual's ability to possess and acquire knowledge about media, as well as the ability to confidently use, critically evaluate, and creatively design media. On the other hand, media literacy stands for the pedagogical–practical goal of actively promoting this potential and imparting the corresponding knowledge and skills in both formal and informal educational contexts [75].

Based on these findings, we can say that with the help of the reflection diary and the combination of lessons and play phases, we have created a learning arrangement in which learners are encouraged to reflect on different levels, to evaluate these critically, and to use media confidently.

The learning diary method is commonly used at universities or in school lessons [56]. Berthold [65] summarized in her study that learning diaries should not be used in a "content-free space" but should be linked to concrete learning and action situations [65].

Based on this knowledge, the learning unit was designed in such a way that the combination of lessons, play phases, and reflection journals was repeated (see Figure 3), which proved to be successful.

In addition, the reflection diary for this study was created based on the literature on the use of learning diaries. The questions in the reflection diary were formulated based on the model of levels of reflection on digital games [24].

Lux and Budke [24] emphasize the importance of critical distance in reflection events in order to reflect on different levels. The teacher used the reflection diary and lessons to regularly take students out of their roles as players and to create a distance from the game. This distance was crucial in order to fill in the reflection diary without being influenced.

Students are therefore encouraged by the teacher to reflect through expertise and reflection prompts.

The reflection journal was used to support and record opportunities for reflection. The teacher can use the reflection journal to address misconceptions and discuss them with the class. Peters and Vissers [76] also emphasize the added value of group reflection to bring together different perspectives.

The successful use of the reflection diary was evident in the high quality of the results. The combination of lessons and play was crucial for the effective completion of the reflection diary. The lessons allowed for questions to be asked and discussed in plenary, both in terms of comprehension and content, and the lessons also served to impart knowledge. The play phases helped to put the newly acquired knowledge into practice through play. By trying out actions and visual representations, the game also served to support subject-specific learning content. With the help of the digital game, the students were able to better visualize the complex topic of "building a city" and thus recognize the limits, dangers, and potential of the digital game. The combination of classroom and game play was rated positively by all students.

As our survey shows, the use of commercial digital games in the classroom can be extremely enriching, as it complements theoretical content with practical game play. In geography education, it is particularly important that the games have a clear reference to reality by simulating or depicting constellations that occur in the real world [12]. A study by Morawski and Wolff-Seidel [44] also shows that video games in geography education have a high potential for promoting deeper understanding, but the games must be thematically appropriately embedded in the lesson [44]. Digital games can increase motivation and engagement in the classroom; this finding should not be ignored [2,9,12,16,33,77].

With regard to our results, we can see that the levels of reflection (see Figure 1) are strongly interrelated. For example, the penetration of the internal level, i.e., the understanding of the game, is essential in order to carry out the external level, i.e., the comparison with the reality outside the game. In this comparison, the subjects already mention the first limitations of the game as a medium (see Figure 1, model level 4).

In summary, it can be said that the results are significantly better than in the first study [22]. Students were able to reflect on the game at different levels.

Compared to the first study [22], the answers are much more detailed and show deeper reflections.

It was shown that students were able to describe polytelic game situations and make decisions in them, i.e., the pursuit of multiple conflicting goals [78]. Polytelic decision situations are characterized by the fact that they do not allow for clear or unambiguous solutions, which is in line with the principles of problem-based learning as explained by Savery [79]. Situations are characterized by conflicting goals. The player must choose between them. The careful consideration of different interests and possible solutions is therefore required in these games [19]. The students were obviously able to deal with the controversial demands well and to describe them in their reflections.

Further positive results can be seen in the external level of reflection, where learners reflect more deeply and recognize the limitations of the medium. It can be said that the influence of teaching and the related expertise are indispensable for professional reflection. The expertise acquired allows students to make a comparison between the digital game world and reality.

Based on this, they are able to reflect on the external level (see Figure 1). In areas where there is little prior knowledge, there is also a lack of depth of reflection. For example, the students did not mention that in the real world one's actions are also limited, for example, by laws.

On the level of self-reflection, the test subjects now differentiate between the roles of student and player; they recognize different character traits with regard to the different roles and derive from them, for example, learning strategies or career aspirations. On the fourth level, the students also reflect on the game primarily as a learning medium, presumably because it was used in a school context. However, what the students repeatedly emphasize as particularly positive is the grading-free space. Students can try out actions and decisions and see the consequences in real time. The students' general reflection on the medium was limited. They were not able to talk about the game in an abstract way—e.g., that all digital games have to be reduced in complexity in order to be playable—nor did they mention the typical game mechanics, such as the reward system that motivates players to continue playing.

It can be assumed that the use of the reflection diary and the combination of teaching and play phases led to these successful results.

In future studies, it might be interesting to investigate the use of the reflection diary in group work, as Peters and Vissers [76] already mentioned the great importance of group reflection in bringing together different perspectives.

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Graph-Community-Enabled Personalized Course-Job Recommendations with Cross-Domain Data Integration

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Abstract: With millions of students/employees browsing course information and job postings every day, the need for accurate, effective, meaningful, and transparent course and job recommender systems is more evident than ever. The current recommendation research has attracted wide attention in the academic and industrial areas. However, existing studies primarily focus on content analysis and user feature extraction of courses or jobs and fail to investigate the problem of cross-domain data integration between career and education. At the same time, it also fails to fully utilize the relations between courses, skills, and jobs, which helps to improve the accuracy of the recommendation. Therefore, this study aims to propose a novel cross-domain recommendation model that can help students/employees search for suitable courses and jobs. Employing a heterogeneous graph and community detection algorithm, this study presents the Graph-Community-Enabled (GCE) model that merges course profiles and recruiting information data. Specifically, to address the skill difference between occupation and curriculum, the skill community calculated by the community detection algorithm is used to connect curriculum and job information. Then, the innovative heterogeneous graph approach and the random walk algorithm enable cross-domain information recommendation. The proposed model is evaluated on real job datasets from recruitment websites and the course datasets from MOOCs and higher education. Experiments show that the model is obviously superior to the classical baselines. The approach described can be replicated in a variety of education/career situations.

Keywords: education; career; heterogeneous data/heterogeneous graph mining; information recommendation; cross-domain

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1. Introduction

What benefits may education provide in terms of career planning? Finding a satisfying career is a popular response that is both comfortable and obvious. Students'/employees' productivity, employability, and career satisfaction are all boosted by lifelong learning, which is the acquisition of knowledge for personal or professional goals. Students/employees are constantly exploring various educational opportunities to further their knowledge in order to achieve their career goals. Education ought to, in general, support the ecological system of employment [1], whereas the skills gap among academic studies, schooling, and industries needs to be narrowed [2].

With the rapid development of Internet technology, online resources have facilitated access to course and job information for students/employees. At the same time, it also brings the problem of "information overload", which confuses students and employers with the vast amount of online material available and prevents them from quickly identifying the most relevant courses and jobs. Recommender systems, which assist users in locating the most relevant items, are a promising method of filtering information. It will provide a series of specialized recommendations based on each user's individual needs and preferences.

In the domains of education and employment, recommender systems can assist students/employees in making better and more informed decisions, consequently influencing their future. Many classical job/occupation and curriculum/education recommendation systems (JCRs) have been proposed, for instance, the CourseAgent system [3], the CourseRank system [4], and the CaPaR framework [5], etc. Existing JCRs, although meeting the requirements of some students/employees, have a limited impact. Furthermore, most algorithms in previous research used user-based models (UBM), content-based models (CBM), and collaborative filtering (CF). UBM focuses on analyzing learner or job seeker profiles, CBM concentrates on investigating course or job content features, and CF primarily examines course ratings, user learning history, and employment history. However, crucial implicit information that helps enhance the accuracy of the suggestion, such as the linkages between courses, skills, and jobs, is not properly exploited [6,7]. More sophisticated routes, such as *jobs-skills-skills-courses-courses*, can be used to link courses and jobs implicitly. According to this viewpoint, the linkage between courses, skills, and jobs may be far more complicated than the traditional CF approach. Furthermore, a large number of studies have been conducted on course recommendations and job recommendations [8], but rarely do they address the issue of cross-domain data integration between the two.

Therefore, this study proposes a novel Graph-Community-Enabled (GCE) approach to address the career-education cross-domain recommendation problem from the heterogeneous graph mining viewpoint. Two domains have three different nodes that interact through four types of relationships. The recommendation issue is therefore transformed into a graph-based random walk problem. Figure 1 depicts the integration of two disparate data sources, education and career into a heterogeneous network, employing skills as a bridge. However, due to the employment of various vocabulary, there are variations between work skills and course skills. We employ the Infomap algorithm to compute skill communities, which aids in the linking of job and course data. Finally, five meta-path features are manually constructed for recommendations based on a suitably indexed heterogeneous graph. A ranking hypothesis is represented by each feature. After that, using a random walk algorithm, we may deliver multiple customized courses and employment proposals by taking into account future professional aspirations or scheduled educational backgrounds.

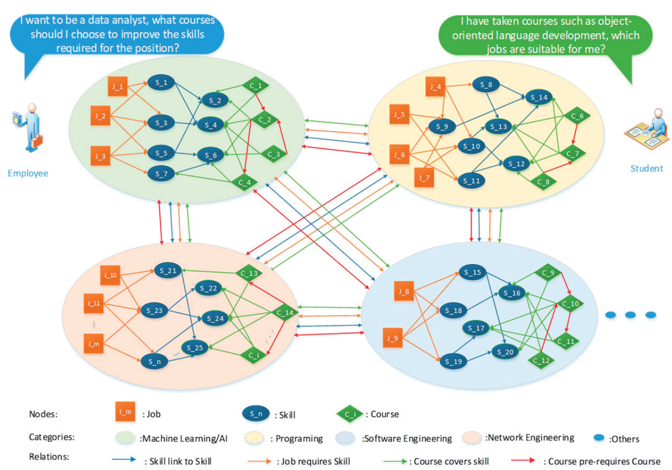


Figure 1. Heterogeneous Graph Index Schema. The *job* nodes are represented by orange squares, *skill* nodes are represented by blue ovals, and *course* nodes are represented by green rhombus. The *job-skill* (required by a job) relations are represented by the directed orange edges. The *skill* (required by a job)-*skill* (covered by a course) relations are represented via the directed blue edges. The *course-skill* (covered by a course) relations are represented by the directed green edges. The *course-course* represents the sequence of courses taken and is indicated by a red directed edge. The large ovals of different colors show the skill community the job and course belong to.

The significance and originality of this study lie in the integration and indexing of information from the job and education domains through heterogeneous networks and community detection to achieve cross-domain information recommendations. Experiments were performed utilizing course data from MOOCs and a university, as well as job advertisements from the IT industry, to illustrate that students/employees may benefit from this graph-based data integration. The findings suggest that the strategy is effective at generating curriculum recommendations based on pre-determined career objectives. The suggested approach is applicable to a variety of educational and occupational settings.

We note that an earlier version of this paper was presented at the International Conference [7], and it is also accessible on the arXiv (https://arxiv.org/, accessed on 11 April 2022) [8]. Our previous conference paper only conducted simple preliminary experiments on the course recommendation task and did not fully validate the proposed model. This manuscript introduces Word2Vec/Bert technology combined with a community detection algorithm to solve the skill difference problem in both course and job domains and improve the connection quality of heterogeneous graphs. In addition, multiple different meta-paths are designed for both course and job recommendation tasks according to the application scenarios of different types of users, while more data (i.e., MOOCs are added) and more baseline methods are used to analyze and validate the effectiveness of the proposed model, which enriches the experimental content. The details are presented in Section 3.

The structure of this paper is as follows: Section 2 reviews related literature; Section 3 details the process of data collection and the proposed community-based graph method; Section 4 discusses the results and provides our conclusions and suggestions for future work.

2. Related Work

2.1. Course Recommendation

In the area of course planning, recommendation systems have been widely used [6,9,10]. Courses were recommended to end-users in the majority of these studies based on feedback from other users [11,12], general user performance [13,14], or similarities across course content [15,16]. For instance, Nguyen et al. [17] employed sequential rule mining to find the optimum course for a pair of courses and grades. Recurrent neural networks were utilized by Morsy and Karypis [18] to suggest courses that could help students maintain and improve their GPAs. In general, it is rare for course recommendation systems to take the target occupation into account [1,19].

Likewise, systems for job recommendation have inspired widespread attention in the academic community in recent decades. Some studies have investigated job recommendations in terms of career pathways. Paparrizos et al. [20] trained machine learning models using prior work experience to predict candidates' next job transfer. Patel et al. [5] introduced CaPaR, a "career path recommendation" framework that mines users' work experience leveraging text mining and collaborative filtering approaches to make two sorts of suggestions to users: work and skill recommendations. To create career suggestions, some systems employed social networks [21]. Lu et al. [22] suggested a graph-based method for generating job recommendations based on the relationships between three entities in society (users, companies, and jobs). Prior job recommendation research has mostly focused on the work experience of users and ignored their educational background. Furthermore, a portion of the research employs graph-based methodologies; however, they are limited to one area of career.

2.2. Graph-Based Recommendation

The link analysis method in graph theory is used in the graph-based recommendation model to address the drawbacks (such as sparsity) of the classic methodology based on cooperation probability and to enhance recommendation accuracy. Early attempts to investigate graph-based recommendation techniques used homogeneous and bipartite graphs, with nodes representing items or users and edges representing similarities between items or between users and items they evaluated [23]. Since heterogeneous graphs contain more node types and edge types, they are able to store richer semantic features compared to homogeneous networks. Recommendation research based on heterogeneous graphs has been widely used in several fields in recent years [24], including social recommendation [25–27], interest recommendation [28], friend recommendation [29], etc. Naturally, there have been numerous graph-based course and job recommender systems designed. For example, Bridges et al. [30] leveraged historical data on grades and enrollment to generate a directed graph, and then used that graph and a student's grades history to provide individualized recommendations about which course he should enroll in. By running a random walk on a Markov chain for each degree program throughout the course enrollment history, Polyzou et al. [31] recommended a shortlist of lessons to be enrolled for the next semester. Shalaby et al. [32] developed a graph-based method for real-time job recommendations that exploits the relationship between user–work interactions and recruitment information to arrive at a scalable solution. In general, existing graph-based course and job recommendation studies are limited to the education domain or the career domain only. In addition, to our knowledge, there are no graph-based studies on cross-domain information recommendations integrating educational and occupational data.

2.3. Cross-Domain Based Recommendation

The cross-domain recommender system is intended to enhance the target domain recommendation results in terms of accuracy and diversity by incorporating the profiles of users across multiple domains, sensing every user's characteristics intelligently, and fulfilling their requirements accurately. There are three main categories of cross-domain recommender algorithms: methods based on collaborative filtering relation, semantic relation, and deep learning. The collaborative filtering relationship mainly refers to the nearest neighbor relationship and the implicit semantic model of users or items. Semantic relation mainly refers to item attribute, tag information, semantic network (computer science) relation, association relation, etc. However, the recommendation performance of the same method varies in different cross-domain recommendation scenarios. Different solutions are usually required for different recommendation scenarios. According to the degree of overlap of users/items between domains, the application scenarios of the cross-domain recommendation system can be grouped into three categories: non-overlapping, partially overlapping, or fully overlapping users/items between domains [33].

In non-overlapping user/items scenarios, it is common to mine hidden common users/items or other hidden relationships between domains for migration learning. Using metadata as a bridge between domains, Fernández-Tobías et al. [34] constructed a cross-domain mixed matrix factorization model. Kuma et al. [35] used the LDA topic method to model the tag information of users and constructed the topic distribution space of user-profiles shared by different fields. Based on this space, users with similar preferences in different fields can be found to achieve cross-domain recommendations. For partially overlapping users/items, these shared users/items are often used as a bridge for information sharing and migration between domains. Jiang et al. [36] proposed a semi-supervised transfer learning method based on joint matrix decomposition, in which users with similar interest preferences in the source domain should have similar interest preferences in the target domain. Krishnamurthy et al. [37] trained user and item feature vectors based on the language model and transferred user feature information from a source domain to the target domain through a training knowledge transfer matrix with overlapping users as the bridge. In fully overlapping users/items scenarios, two domains are usually merged to turn cross-domain recommendations into single-domain recommendations. Jiang et al. [38] created a star-structured hybrid network that fused social network data and transferred knowledge from source domains to the target domain through a hybrid random walk method.

Notwithstanding a rich body of literature on cross-domain recommender systems, there is no specific design for career-education recommendation problems. Therefore, they cannot be directly applied to the problems studied in this study.

This study advances previous work by proposing a novel graph-based methodology that uses a heterogeneous graph combining educational and occupational data to recommend courses or occupations for students (or entry-level employees) in a hierarchical order based on their educational/occupational experience.

3. Research Methods

In this section, we will explore in-depth the proposed method, including data collection on education and occupation (Section 3.1), integrating and indexing two datasets through a heterogeneous graph with skills communities computed by Infomap. (Section 3.2), grading personalized curriculum and jobs using a graph-community-enabled cross-domain rating function that employs a random walk method (Section 3.3), and performing a case study (Section 3.4).

3.1. Data Collection

There are two types of data in the dataset collected in this study:

Courses/Education data were gleaned from the Luddy School of Informatics, Computing, and Engineering (SICE) at Indiana University Bloomington's (IUB) course enrollment log and course catalog (https://luddy.indiana.edu/academics/courses/search/iub-fall-2019, accessed on 11 April 2022). In total, these data include 188,881 course enrollment records from six departments (or fields) (Computer Science, Data Science, Informatics, Information and Library Science, Intelligent Systems Engineering, and Statistics) with 7824 students in 371 courses over 10 semesters in the 2016–2019 academic years. The collected curriculum data are structured. However, a significant feature not described in the original university curriculum data is the skills that a course teaches. In order to achieve the linkage of IUB-SICE courses and skills, we downloaded 957 MOOCs (https://www.coursera.org/, accessed on 11 April 2022) (each MOOC has a specific skill set, with a total of 1101 skills) in the same fields as IUB-SICE courses through web crawling (https://www.webscraper.io/, accessed on 11 April 2022). The Greedy Matching algorithm that is shown in Algorithm 1 was leveraged to extract the corresponding skills in IUB-SICE courses. The principle of the algorithm is to match from the right to the left of the text based on the dictionary, taking the length of the longest phrase in the dictionary as the length of the first matched text in each round, decreasing word by word from the left each time, scanning through the corresponding dictionary, and making the longest possible phrase that is matched as the best option. Specifically, the relevant skills from MOOCs as a skill-vocabulary V are greedily matched with the content C (course title and course description) of each IUB-SICE course, and the related skills of all courses of IUB-SICE are projected from MOOCs. After that, in this study, the course registration information of students who took less than five courses was removed. Courses with empty course descriptions and course skills were also removed. Finally, there were four features for any course included in the education dataset, namely course ID, course name, course description, and all associated skills. Overall, the education dataset consists of 266 university curricula, 957 MOOCs, and 1011 relevant skills.

The Job/Career dataset was composed of job postings scraped from Careerbuilder (https://www.careerbuilder.com/, accessed on 11 April 2022) in December 2019 using automated crawler technology. Trending IT job titles (https://money.usnews.com/money/careers/slideshows/discover-the-best-technology-jobs, accessed on 11 April 2022) were used as search terms. Redundant postings without the required skills were deleted, resulting in a total of 20,000 jobs and 1611 skills related to them listed in the final data. Finally, five characteristics were derived from job advertisements: Job ID, Job Title, Company, Location, and the set of needed Skills.

Algorithm 1. Greedy Matching Algorithm

Input:
the skill vocabulary *V* from MOOCs;
the content *C* of each IUB-SICE course (course name+ course description).
Output:
the corresponding skill *S* of each IUB-SICE course.
skills ⇐ [];
convert content *C* to list *C_List;* convert vocabulary *V* to list *V_List*;
let the pointer *P* point to the end of *C_List*;
calculates the number of words from the pointer *P* to the beginning of *C_List* (that is, the length of the unsliced content) as *n*;
calculates the number of words in the longest phrase in *V_List* as *m*;
while *P* is not at the beginning of the *C_List* **do**
  if *n* < *m* **then**
    m = *n*;
  end
    takes *m* words from the current *P* to the left of *C_List* as the phrase *W*
  if *W* is in the *V_List* **then**
    adds *W* to *skills*;
    modifies the pointer *P* based on the length of *W*;
  else
    removes one word from the left end of *W*;
  end
end
return *skills*.

3.2. Skill Community Detection and Data Indexation Based on Heterogeneous Graph

The key to designing this cross-domain recommendation system was to integrate data from the career domain and the education domain by building a heterogeneous graph. The essential link between the two domains was the range of skills needed for a career and the set of skills taught by each curriculum [1,6]. However, the skills stated in the courses use separate vocabularies from the skills listed in the jobs. Only 79 overlapped skills were detected in our dataset, which spanned career and curriculum data.

To overcome this problem and to link the two domains more closely, a community detection technique, the Infomap algorithm [39], was used for skill community partitioning in the candidate graph M. The Infomap approach works by simulating a random walker's m steps on a graph and indexing his random walk paths with a two-level codebook (a globally indexed codebook, one for each community). The following formula was used to construct a community division with the shortest description length of random walks:

$$L(\pi) = \sum_{i}^{m} q^{i} H(\mathcal{Q}) + \sum_{i=1}^{m} p^{i} H\left(\mathcal{P}^{i}\right), \tag{1}$$

where $L(\pi)$ represents a random walker's description length in the present community division π. q^i and p^i are the inter-and intra-group jump rates of the i_{th} community at each step. $H(\mathcal{Q})$ represents the frequency-weighted average length of codewords from the globally indexed codebook, while $\mathrm{H}\left(\mathcal{P}^{i}\right)$ represents the frequency-weighted average length of codewords from the i_{th} community codebook.

To begin, we generated a career network graph and an education network graph. All skill nodes were categorized into communities using Infomap (e.g., computer science community, data science community, and artificial intelligence community). The most similar vocational and educational communities (by counting the skills with similarity exceeding 0.9 via BM25/Word2Vec/Bert algorithm) were then combined with the related jobs and courses (as shown in Figure 1).

All educational and occupational data (skills, courses, and jobs) were combined into a single heterogeneous graph $\mathrm{G} = (\mathrm{V},\ \mathrm{E})$ utilizing this approach. We define a node-type mapping function $\tau : V \to O$ and an edge-type mapping function $\phi : E \to R$ in this graph, where each node $v \in V$ corresponds to a particular variable $\tau(v) \in O$ and each edge $e \in E$ corresponds to a particular relation $\phi(e) \in R$. Both the start and end objects type are the same if two linkages are of the identical relation type. Table 1 shows the descriptions of the nodes and relations.

Table 1. Nodes and Relations in the constructed heterogeneous graph.

Nodes and Relations	Description
C	The course nodes
J	The job nodes
S	The skill nodes
$C \xrightarrow{p} C$	The course to course edge via the pre-required relation
$C \xrightarrow{c} S$	The course to skill edge via the covered relation
$J \xrightarrow{r} S$	The job to skill edge via the required relation
$S \xrightarrow{l} S$	Skill to skill edge (skill-skill text similarity within each community based on BM25/Word2Vec/Bert).

The sum of the weights of outgoing connections of the same type for each node shown on the graph is equal to 1. For example, a link from C_i to C_j has a weight that is defined as $w\left(C_i \xrightarrow{p} C_j\right) = \frac{d\left(C_i \xrightarrow{p} C_j\right)}{d\left(C_i \xrightarrow{p} C\right)}$, in which $d\left(C_i \xrightarrow{p} C_j\right)$ is the count of students registered in a course C_j prior to registration in a course C_i, and in which $d\left(C_i \xrightarrow{p} C\right)$ is the sum of students registered in any course prior to registration in a course C_i. A link of $C_i \xrightarrow{c} S_j$ has a weight that is defined as $w\left(C_i \xrightarrow{c} S_j\right) = \frac{1}{d\left(C_i \xrightarrow{c} S\right)}$C, where $d\left(C_i \xrightarrow{c} S\right)$D represents the sum count of skills that the course C_i taught. An edge of $J_i \xrightarrow{r} S_j$ has a weight that is defined as $w\left(J_i \xrightarrow{r} S_j\right) = \frac{d\left(J_j \xrightarrow{r} S_j\right)}{d\left(J_i \xrightarrow{r} S\right)}$, in which $d\left(J_i \xrightarrow{r} S_j\right)$ is the number of jobs J_i requiring skill S_j, where $d\left(J_i \xrightarrow{r} S\right)$ is the overall quantity of job J_i demanding any skill. The key to linking the whole heterogeneous graph internally is the linkage $S \xrightarrow{l} S$. For $S \xrightarrow{l} S$, the weight is the normalized similarity score among skills inside of each community (via BM25/Word2Vec/Bert). Similar skill pairs with noise do not affect the accuracy of the graph due to community restrictions.

The final network graph contained 23,845 nodes and 123,208 edges. There are 20,000 occupations, 266 university courses, 957 MOOCs, and 2622 skills (from jobs and courses) among them, with 73,560 $J \xrightarrow{r} S$, 11,155 $C \xrightarrow{p} C$, 10,641 $C \xrightarrow{c} S$, and 27,825 $S \xrightarrow{l} S$ linkages between them.

3.3. Community-Constrained Cross-Domain Recommendations with Heterogeneous Graph-Enabled

To generate educational/career recommendations, this section uses the Graph Community Enabled (GCE) cross-domain rating technique. We gathered the target candidate nodes for each query node in the graph and provide recommendations based on their ranking scores. A ranking function based on meta-paths [40] and community structure was used to calculate the ranking score of each candidate node. Briefly, a meta-path is a specific path connecting two entities. In this paper, meta-path refers to the relationship between query nodes and candidate nodes within a heterogeneous graph. Additionally, more than one different meta-path is generally included with the identical recommendation task (e.g., to suggest a curriculum to various users with different preferences). Furthermore, by changing the types of query nodes and suggestion nodes, the technique can be applied to different recommendation tasks, such as proposing occupations to students or professionals.

The random walk algorithm is capable of efficiently catching complicated, higher-order, and indirect interactions between different types of nodes in a graph. It can successfully handle challenges in graph learning recommender systems (GLRS), particularly GLRS constructed on heterogeneous graphs, such as information propagation among different types of nodes [41]. Typically, random walk-based recommender systems start by having random walkers walk on a particular graph with a predefined probability of transfer at each step to simulate implicit preference or interaction propagation between users and/or items, and then rank these candidate nodes for recommendation using the probability of the walker landing on a node after a particular step. Therefore, a random walk-based metric is presented to measure the ranking scores of candidate nodes along meta-paths [40]. The following is a formula for it:

$$s\left(v_i^{(1)} \to v_j^{(l+1)}\right) = \sum_{t=v_i^{(1)} \to v_j^{(l+1)}} RW(t), \tag{2}$$

where v_i denotes the seed node, and v_j represents the query node of the candidate and in which t denotes a wander from v_i to v_j. Assuming $t = \left(v_{i1}^{(1)}, v_{i2}^{(2)}, \ldots, v_{il+1}^{(l+1)}\right)$, then the probability of the random walk is $RW(t) = \prod_{\mathrm{j}} w\left(v_{ij}^{(j)}, v_{ij+1}^{(j+1)}\right)$, where $w\left(v_{ij}^{(j)}, v_{ij+1}^{(j+1)}\right)$ is the weight of the edge $v_{ij}^{(j)} \to \mathrm{v}_{ij}^{(j+1)}$.

We explored course recommendation as a proof of concept and specified distinct meta-paths for the course recommendation task in three scenarios. In addition, for the job recommendation study, different meta-paths have also been designed for the two cases (see Table 2).

Table 2. Meta-path in the constructed heterogeneous graph.

	Scenarios	Meta-Paths	Ranking Hypothesis
Course Recommendation	1	$\mathbb{C}_J \,\|\, J \xrightarrow{r} S \xrightarrow{l} S \xleftarrow{c} C_?$	The candidate courses in the community where the query job is located will be related to the query job if the skills covered by the courses are related to the skills required by the query job.
		$\mathbb{C}_{/J} \,\|\, C^p_? \xrightarrow{p} C_?$	The pre-required course of the candidate courses not in the community where the query job is located will be related to the query job.
	2	$\mathbb{C}_{/J} \,\|\, C^p \xrightarrow{c} S \xleftarrow{c} C_?$	The candidate courses not in the community where the query job is located will be related to the job if they share similar skills as the taken course.
	3	$\mathbb{C}_J \,\|\, J \xrightarrow{r} S \xrightarrow{l} S \xleftarrow{c} C \xleftarrow{p} C_?$	The candidate courses in the community where the query job is located will be related to the job if the skills of the pre-required courses of candidate courses are related to the skills required by the query job.

Table 2. *Cont.*

	Scenarios	Meta-Paths	Ranking Hypothesis
Job Recommendation	4	$\mathbb{C}_C \Big\|\Big\| C \xrightarrow{c} S \xrightarrow{l} S \xleftarrow{r} J_?$	The candidate jobs in the community where the courses that have been taken will be related to the courses, if the skills covered for the query courses are related to the skills required by the job.
	5	$\mathbb{C}_{/J} \Big\|\Big\| C \xrightarrow{c} S \xrightarrow{l} S \xleftarrow{r} J_?$	The candidate jobs not in the community where the current job is located will be related to the courses if the skills covered for the query courses are related to the skills required by the job.

Scenario 1 : *A freshman undergraduate or first-year graduate student with a career target (job node) is seeking educational advice (course node) to help him or her accomplish that goal.*

The input to Scenario 1 is the student's target occupation (job node) and its output is the list of suggested curricula (course nodes). The associated meta-path functions are shown in Table 2. The queried job node is represented by J, and the candidate curriculum node is represented by $C_?$. These path functions gather the candidate courses connected to the career objective by skill traversing the relationship between jobs and courses. It is worth noting that the first function only retrieves for the objective community $\mathbb{C}_J$, which has the job J, whereas the second path function operates only for all pre-requisite courses $C^p_?$ in the community $\mathbb{C}_{/J}$, which do not have the job J;

Scenario 2: *An employee/student has completed certain courses* C^p *and is seeking the potential courses* $C_?$ *to help him (or her) accomplish his (or her) career objective* J. *A new path function is added compared to the path function of Scenario 1:* $\mathbb{C}_{/J} \Big\|\Big\| C^p \xrightarrow{c} S \xleftarrow{c} C_?$, *in which* C^p *has a better likelihood of assisting in finding suitable courses* $C_?$;

Scenario 3: *An employee/professional is currently employed at job* J *and wishes to advance in his or her career. That is, he is searching for a course that will assist him in upskilling.* $\mathbb{C}_J \Big\|\Big\| J \xrightarrow{r} S \xrightarrow{l} S \xleftarrow{c} C \xleftarrow{p} C_?$ *can be seen as the ranking function. Since the information demands of users are to upgrade their skills, the final stage will be* $C \xleftarrow{p} C_?$, *namely, basic courses (e.g., programming) can move on to more advanced courses (e.g., machine learning);*

Scenario 4: *A graduating undergraduate/graduate student is looking for a new job (job node). The input is the student's completed courses (course nodes), and its output is the list of suggested jobs (job nodes). The meta-path function for Scenario 4 is shown in* Table 2. *Where* C *denotes the queried course node, and* $J_?$ *represents the recommended job node. The path function gathers candidate jobs associated with courses already taken by traversing the relationship between jobs and courses through skills. It is worth noting that the function only works on the target community* $\mathbb{C}_C$, *which includes course* C;

Scenario 5: *An employee currently has a job and has enrolled in some courses and is looking for a new career not related to the current job. This is similar to Scenario 4, but this function is executed only for community* $\mathbb{C}_{/J}$, *which does not contain the current job* J.

In contrast to prior research, the community constraint of the random walk function described in this work is critical for efficiently reducing noise and improving recommendation accuracy.

3.4. Experimental Result

Experiments were run for Scenarios 1 to 5, respectively. Four university lecturers with at least 10 years of teaching experience and 10 years of industrial experience and 20 graduate students with at least 2 years of industrial experience were invited to perform a case study with the presented recommendation algorithm. Following [42], Mean Average Precision (MAP@K), Precision (P@K) and Normalized Discounted Cumulative Gain (NDCG@K) were used as the evaluation metrics. The performance of the ranking at a particular cutoff level was also estimated, considering only the top K courses returned as candidates in the experiment. We set K to 5, 10, 15, 20 and calculate all metrics. P@K(q) was computed as follows:

$$\mathrm{P@K(q)} = \frac{\sum_{\mathrm{k}=1}^{\mathrm{K}} \mathrm{acc_q(k)}}{\mathrm{K}}, \tag{3}$$

where $\mathrm{acc_q(k)}$ is a binary indicator function that returns 1 when the k-th recommendation is relevant for the q-th query and 0 otherwise. MAP@K is computed as the average AP@K(q) per query, where AP@K(q) is computed as follows:

$$\mathrm{AP@K(q)} = \frac{1}{\min(\mathrm{R_q}, \mathrm{K})} \sum_{\mathrm{k}=1}^{\mathrm{K}} \mathrm{P_q@k} \times \mathrm{Rel_q(k)}, \tag{4}$$

where $\mathrm{R_q}$ is the total number of corresponding courses/jobs that appear in the q-th query, $\mathrm{P_q@k}$ is the precision at rank k for the q-th query, and $\mathrm{Rel_q(k)}$ is a binary indicator function that returns 1 when the k-th recommendation is relevant for the q-th query and 0 otherwise. NDCG@K(q) is computed as follows:

$$\mathrm{NDCG@K(q)} = \frac{\mathrm{DCG@K(q)}}{\mathrm{IDCG@K(q)}} = \frac{\sum_{\mathrm{k}=1}^{\mathrm{K}} \frac{2^{\mathrm{Rel_q(k)}}-1}{\log_2(k+1)}}{\sum_{\mathrm{k}=1}^{|\mathrm{Rel_q}|_{\mathrm{K}}} \frac{2^{\mathrm{Rel_q(k)}}-1}{\log_2(k+1)}}, \tag{5}$$

where $|\mathrm{Rel_q}|_{\mathrm{K}}$ represents the length of the recommendation list that are most relevant to the q-th query among the top k candidate recommendations.

3.4.1. Comparison with Baselines

This experiment evaluates our model Graph-Community-Enabled (GCE) against the Text-based and Graph-Enabled (GE) models. The comparison methods are given below.

- Text ranking features:

BM25 [43]: the text query is sent to the course/job text indexation, and relevant courses/jobs are fetched. Then, extracting the keyword information from each retrieved (and top-ranked) course content or job posting as a new query. In the end, matching precisely the words between the new query and each course/job document.

Word2Vec [44] and BERT [45]: firstly embedding the descriptions of a course and a job into two vectors, and then calculating the cosine similarity between the two vectors. Finally, ranking the relevant course/job related to the query according to similarity.

- Graph-Enabled (GE) ranking features:

GE(BM25): matching the words of skills between courses and work through BM25, linking the education network and work network. A ranking is then performed on the scores of each candidate node, which are derived from the meta-path ordering function based on the random walk algorithm.

GE(W2V): the skills of course and job are embedded through Word2vec, and the cosine similarity between them is calculated. Each course skill retains the top five job skills and establishes a skill graph connecting education and vocational fields. In addition, random walk algorithms are used to rank each candidate node's scores that come from the meta-path.

GE(Bert): except for the embedding of skills from courses and jobs being calculated through the Bert model, other processes are the same as GE (W2V).

- Graph-Community-Enabled (GCE) ranking features:

GCE(BM25): integrating the education-career heterogeneous graph by matching the words of skills between courses and work through **BM25**. Using the Infomap algorithm to detect the communities in the graph. Then, a random walk is run on the graph with the classified communities and the scores of each candidate are ranked.

GCE(W2V): the skills of course and job are embedded through Word2vec, and the cosine similarity between them is calculated. Each course skill retains the top five job skills and establishes a skill graph connecting education and vocational fields. Using the Infomap algorithm to detect the communities in the graph. Then, a random walk is run on the graph with the classified communities and the scores of each candidate are ranked

GCE(Bert): except that the embedding of skills from courses and jobs is calculated through the Bert model, other processes are the same as GCE(W2V).

3.4.2. Recommending Courses to User

For Scenario 1 to 3, participants tested five text queries (job title, e.g., "Database Administrator", "Java Developer", and "Data Scientist", etc.) for each scenario. Additionally, they entered the courses (course name, e.g., "Database Concepts", "Programming Language Principles", "Introduction to Data Analysis and Mining", etc.) that had been taken for scenario 2. Then, the results of each recommendation were rated as "relevant" or "not relevant" by each respondent against the query terms. Combining each participant's feedback, we calculated the recommendation performance of each scenario. In Tables 3–5, the performance of multiple recommendation algorithms is reported, including overall and top-ranked course recommendation performances. Figure 2a–c show the top-20 courses' performances of the graph-based recommendation approaches in three scenarios.

Table 3. Result of Course Recommendation for Scenario 1.

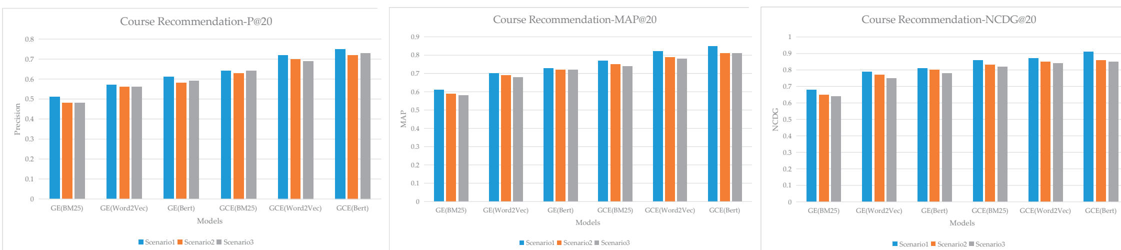
Method	P@5	MAP@5	NCDG@5	P@10	MAP@10	NCDG@10	P@15	MAP@15	NCGD@15	P@20	MAP@20	NCDG@20
BM25	0.38	0.52	0.58	0.43	0.55	0.61	0.45	0.57	0.64	0.48	0.58	0.65
Word2Vec	0.41	0.55	0.61	0.48	0.57	0.65	0.48	0.6	0.67	0.5	0.62	0.68
Bert	0.48	0.62	0.73	0.5	0.63	0.74	0.51	0.65	0.77	0.55	0.66	0.79
GE(BM25)	0.39	0.53	0.58	0.48	0.56	0.62	0.49	0.59	0.65	0.51	0.61	0.68
GE(W2V)	0.43	0.65	0.74	0.52	0.64	0.76	0.55	0.69	0.78	0.57	0.70	0.79
GE(Bert)	0.51	0.67	0.75	0.57	0.69	0.77	0.58	0.71	0.79	0.61	0.73	0.81
GCE(BM25)	0.55	0.71	0.79	0.59	0.73	0.82	0.61	0.76	0.85	0.64	0.77	0.86
GCE(W2V)	0.63	0.75	0.81	0.66	0.78	0.85	0.68	0.81	0.87	0.72	0.82	0.87
GCE(Bert)	**0.67**	**0.78**	**0.83**	**0.69**	**0.81**	**0.89**	**0.72**	**0.83**	**0.9**	**0.75**	**0.85**	**0.91**

Table 4. Result of Course Recommendation for Scenario 2.

Method	P@5	MAP@5	NCDG@5	P@10	MAP@10	NCDG@10	P@15	MAP@15	NCGD@15	P@20	MAP@20	NCDG@20
BM25	0.39	0.51	0.55	0.44	0.54	0.59	0.46	0.56	0.63	0.47	0.57	0.64
Word2Vec	0.4	0.54	0.58	0.47	0.55	0.62	0.48	0.58	0.65	0.5	0.60	0.66
Bert	0.46	0.61	0.69	0.49	0.64	0.71	0.52	0.67	0.74	0.54	0.67	0.75
GE(BM25)	0.37	0.51	0.57	0.41	0.54	0.59	0.45	0.57	0.63	0.48	0.59	0.65
GE(W2V)	0.42	0.61	0.69	0.49	0.62	0.72	0.54	0.68	0.75	0.56	0.69	0.77
GE(Bert)	0.5	0.65	0.72	0.54	0.69	0.75	0.56	0.70	0.78	0.58	0.72	0.80
GCE(BM25)	0.53	0.68	0.74	0.57	0.72	0.78	0.60	0.73	0.82	0.63	0.75	0.83
GCE(W2V)	0.59	0.73	0.77	0.62	0.75	0.79	0.67	0.78	0.83	0.70	0.79	0.85
GCE(Bert)	**0.61**	**0.75**	**0.80**	**0.66**	**0.77**	**0.83**	**0.70**	**0.79**	**0.85**	**0.72**	**0.81**	**0.86**

Table 5. Result of Course Recommendation for Scenario 3.

Method	P@5	MAP@5	NCDG@5	P@10	MAP@10	NCDG@10	P@15	MAP@15	NCGD@15	P@20	MAP@20	NCDG@20
BM25	0.37	0.52	0.54	0.42	0.56	0.58	0.46	0.58	0.61	0.47	0.59	0.63
Word2Vec	0.39	0.53	0.56	0.48	0.58	0.60	0.51	0.6	0.63	0.53	0.62	0.64
Bert	0.47	0.63	0.65	0.50	0.62	0.68	0.53	0.65	0.70	0.55	0.66	0.72
GE(BM25)	0.38	0.5	0.53	0.41	0.53	0.59	0.47	0.56	0.63	0.48	0.58	0.64
GE(W2V)	0.43	0.64	0.66	0.51	0.63	0.70	0.55	0.66	0.73	0.56	0.68	0.75
GE(Bert)	0.5	0.66	0.69	0.55	0.68	0.74	0.58	0.70	0.77	0.59	0.72	0.78
GCE(BM25)	0.52	0.69	0.71	0.58	0.71	0.76	0.64	0.72	0.81	0.64	0.74	0.82
GCE(W2V)	0.61	0.72	0.75	0.64	0.75	0.78	0.68	0.77	0.82	0.69	0.78	0.84
GCE(Bert)	**0.63**	**0.76**	**0.79**	**0.66**	**0.79**	**0.82**	**0.71**	**0.80**	**0.83**	**0.73**	**0.81**	**0.85**



(**a**) (**b**) (**c**)

Figure 2. Comparison of graph-based course recommendation methods. (**a**) Course Recommendation Precision@20; (**b**) Course Recommendation MAP@20; (**c**) Course Recommendation NCDG@20.

The results show that the proposed GCE method performs clearly better than other baselines, and GCE(Bert) works best. Besides, the text-only ranking model performs poorly compared to graph-based ranking methods, with the exception of GE (BM25), because it cannot capture the higher-order relationships across job and course domains using only job and course descriptions. Meanwhile, the GE approaches' performance (MAP, Precision and NCDG) of the top-20 courses underperformed the GCE method. The GCE method performed better in Scenario 1 than in the other two scenarios. Compared with the other two scenarios, the length of the meta-path for Scenario 1 is shorter, and the structure is simple. As pointed out in Sun et al. [46], shorter meta-paths have more information than longer ones because longer meta-paths link more remote objects (with lower semantic relevance).

3.4.3. Recommending Jobs to User

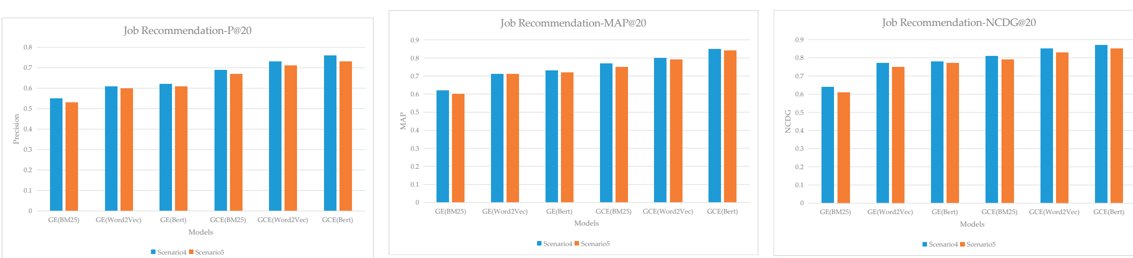
Similar to the course recommendation test, for Scenarios 4 and 5, each participant tested five text queries (course name, e.g., "Database Concepts", "Programming Language Principles", "Introduction to Data Analysis and Mining") for each scenario and additionally entered a current job (job title, e.g., "Database Administrator", "Java Developer", and "Data Scientist") for Scenario 5. Tables 6 and 7 show the results of different recommendation methods. Figure 3a–c shows the top-20 job performance of the graph-based recommendation approaches in two scenarios. Based on these tables, the results are similar to course recommendations, and the GCE method outperforms the baselines on the job recommendation task. GE(BM25) still works worst, as the skills from courses and jobs were represented in different vocabularies, and only a few skills overlap. In addition, from the data in Figure 3a–c, it is apparent that the performance of GCE in Scenario 4 is better than in Scenario 5 and is obviously superior to other methods.

Table 6. Result of Job Recommendation for Scenario 4.

Method	P@5	MAP@5	NCDG@5	P@10	MAP@10	NCDG@10	P@15	MAP@15	NCGD@15	P@20	MAP@20	NCDG@20
BM25	0.35	0.48	0.51	0.51	0.55	0.56	0.52	0.57	0.59	0.53	0.58	0.61
Word2Vec	0.38	0.58	0.62	0.52	0.59	0.65	0.54	0.62	0.69	0.54	0.64	0.7
Bert	0.41	0.62	0.65	0.54	0.63	0.68	0.58	0.66	0.72	0.59	0.67	0.73
GE(BM25)	0.36	0.5	0.54	0.49	0.57	0.58	0.53	0.61	0.62	0.55	0.62	0.64
GE(W2V)	0.42	0.64	0.68	0.56	0.65	0.72	0.59	0.69	0.76	0.61	0.71	0.77
GE(Bert)	0.49	0.68	0.71	0.59	0.69	0.73	0.62	0.73	0.77	0.62	0.73	0.78
GCE(BM25)	0.52	0.7	0.73	0.63	0.72	0.77	0.67	0.75	0.80	0.69	0.77	0.81
GCE(W2V)	0.61	0.73	0.77	0.67	0.75	0.79	0.71	0.79	0.83	0.73	0.80	0.85
GCE(Bert)	**0.65**	**0.75**	**0.78**	**0.71**	**0.79**	**0.83**	**0.73**	**0.84**	**0.86**	**0.76**	**0.85**	**0.87**

Table 7. Result of Job Recommendation for Scenario 5.

Method	P@5	MAP@5	NCDG@5	P@10	MAP@10	NCDG@10	P@15	MAP@15	NCGD@15	P@20	MAP@20	NCDG@20
BM25	0.34	0.49	0.50	0.52	0.54	0.54	0.53	0.56	0.57	0.53	0.57	0.59
Word2Vec	0.36	0.58	0.61	0.53	0.58	0.63	0.55	0.60	0.67	0.56	0.62	0.69
Bert	0.4	0.61	0.63	0.55	0.62	0.67	0.56	0.65	0.70	0.58	0.66	0.71
GE(BM25)	0.34	0.49	0.52	0.48	0.56	0.55	0.51	0.59	0.59	0.53	0.60	0.61
GE(W2V)	0.44	0.64	0.66	0.57	0.66	0.70	0.58	0.69	0.73	0.60	0.71	0.75
GE(Bert)	0.47	0.66	0.69	0.58	0.67	0.72	0.60	0.71	0.76	0.61	0.72	0.77
GCE(BM25)	0.51	0.69	0.72	0.64	0.7	0.75	0.66	0.73	0.78	0.67	0.75	0.79
GCE(W2V)	0.6	0.72	0.75	0.67	0.76	0.78	0.69	0.78	0.81	0.71	0.79	0.83
GCE(Bert)	**0.63**	**0.75**	**0.76**	**0.69**	**0.78**	**0.82**	**0.72**	**0.82**	**0.84**	**0.73**	**0.84**	**0.85**



(**a**) (**b**) (**c**)

Figure 3. Comparison of graph-based job recommendation methods. (**a**) Job Recommendation Precision@20; (**b**) Job Recommendation MAP@20; (**c**) Job Recommendation NCDG@20.

In summary, the GCE approach described in this paper has a better chance for cross-domain recommendation than other traditional methods and can serve the individualized needs of students/professionals. It is also worth noting that we just employed a simple graph ranking model in this experiment. To increase recommendation performance in the future, we will continue to investigate more complicated graph ranking models and learn ranking algorithms.

4. Discussion and Conclusions

In this study, we present a novel model GEC that combines heterogeneous graphs with community detection techniques, aimed at integrating and indexing education and career data according to the group of skills, to implement a variety of information retrieval/recommendation tasks to satisfy students' and job seekers' diverse information requirements.

We chose 24 people to conduct five separate experiments for each scenario on real-world work and course datasets. In other words, 120 experiments were conducted for each scenario. Since the input of each experiment was different, the experimental results were also different. The same inputs were also tested in this study and the results were the same. The experimental results shown in this paper are the average value after all tests.

The experimental results show that, among the three text ranking models in all scenarios, the Bert model works best, followed by Word2Vec, BM25 with the worst results. The text similarity algorithm based on semantic matching outperformed the non-semantic matching similarity algorithm. Similarly, the experimental performance of the three GE baseline models is similar to the three text ranking methods mentioned above, and the recommended performance is GE(Bert), GE(W2V), and GE(BM25) in descending order. The GE baseline methods are better than the text ranking methods overall, except GE(BM25). This is because, based on BM25 algorithm, the course skill nodes are poorly matched with the job nodes, resulting in a poorly linked job network graph and course network graph, which affects the random walk ranking performance. The performance of the proposed model GCE(Bert) is the best, followed by GCE(W2V) and finally GCE(BM25). The performance of GCE(Bert) (i.e., the mean of P@20,MAP@20 and NCDG@20) is higher than that of BM25,Word2Vec,Bert with ((0.25)(0.21)(0.16), respectively. It is also higher than the performance of GE(Bert), GE(W2V), and GE(BM25), which improved by (0.23)(0.13)(0.11), respectively. This validates the effectiveness of the model proposed in this paper. In addition, it is interesting to note that in all five cases of this study, the GCE model works best for students who have not taken a course or have no work experience (Scenarios 1 and 4). A possible explanation for this might be that the information input by such users is refined and has a low impact on the ranking of candidate recommendations.

The present results are significant in at least two major respects. First, in the view of data science, it is necessary to cross-traverse occupational data and educational data. It is also a prospective way to integrate data through community detection and data fusion. Second, by crossing curriculum and job domains, this study helps to eliminate the "Skills Gap" between the students/employees and the employers.

However, this approach is limited in that there are almost no overlapping skills between jobs and courses. Specifically, among the 1011 skills that are recognized from the course data, there are only 79 skills that can be mapped to the skill vocabulary set out in recruitment advertisements. Another limitation of this study is that the experiment used only one real dataset (education and work dataset) to validate the model. Although most of the related studies [47–50] also used only one dataset, in order to further validate the model generalizability, new datasets will be considered for future studies.

Going forward, there are three areas we will be working on with this project. First, we want to improve the quality of heterogeneous graphs: (1) unifying skill terms and skill classifications by using external knowledge bases, e.g., Wikipedia; and (2) adding new node types and edges, e.g., company, (course) instructor, and salary information; (3) to further improve the recommendation performance, we will try to study a more elaborate heterogeneous graph ranking model. Finally, we intend to leverage user feedback to train models and improve recommendation performance.

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Making Urban Water Management Tangible for the Public by Means of Digital Solutions

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Abstract: Digital solutions are increasingly deployed in water management to support decision-making and to realize the automatization of processes. These solutions have a high potential to foster the sustainability of water management and related fields and thus to contribute to achieving the United Nations (UN) Sustainable Development Goals (SDGs). At the same time, more and more digital solutions aim to increase public awareness of specific urban water management aspects. To date, however, evidence is limited on the relevance and effectiveness of such digital solutions and on the effect of the governance settings on the potential of such solutions to raise awareness about the underlying water management issues. This paper aims to provide insights into the findings of two case studies, in Paris and Berlin, investigating the potential of digital solutions to make urban water management visible to the public and thus increase awareness about specific water management issues.

Keywords: sustainable water infrastructure; digitalization; urban water management; public awareness; water governance

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1. Introduction

Megatrends such as urban expansion and population growth as well as more frequent and severe extreme weather events due to climate change present major challenges to the management and governance of urban water systems in cities around the world [1]. To ensure sustainable urban water management [2–4] under complex governance settings, there is a need to critically reflect upon whether current water management approaches take public awareness aspects sufficiently into account.

Infrastructures in urban water systems and the services they provide are conceived to be so normalized in the daily lives of city dwellers that they become ‘invisible’ most of the time, and only perceivable when they fail or break down [5,6]. Their functioning is generally unknown to the public. Yet, such ‘blackboxing’ prevents citizens from understanding the sustainability challenges that these infrastructures and associated water resources may face in the future. This is reinforced by an observed reluctance and lack of resources among policy-makers to introduce measures to raise public awareness [7]. Increased awareness and knowledge of the public about water-related sustainability issues has been identified as an important factor influencing individual water consumption [8]. Yet, little is known about the potential influence of increased awareness and knowledge on public discourses evolving around the sustainability of urban water systems.

Digital solutions are increasingly deployed in urban water management. Generally referred to as “smart water management” [9,10], these solutions have a high potential to foster the sustainability of water management and related fields and thus to contribute to the United Nations (UN) Sustainable Development Goals (SDGs). Many of these digital solutions in the water sector are aimed at helping managers make decisions—for instance on water loss control or water treatment optimization—to increase the efficiency of urban water management [11]. Apart from that, digital solutions are increasingly being developed that aim to foster public participation and knowledge on urban water management [12,13]. These new solutions are assumed to have the potential to contribute directly or indirectly to resource-efficient and sustainable water management (see Figure 1). They can open up the 'black box' and make water infrastructure visible to the general public. Since behavioral changes are key for improving consumption patterns, making infrastructure and data more visible has the potential to render urban water management more sustainable in the long run.

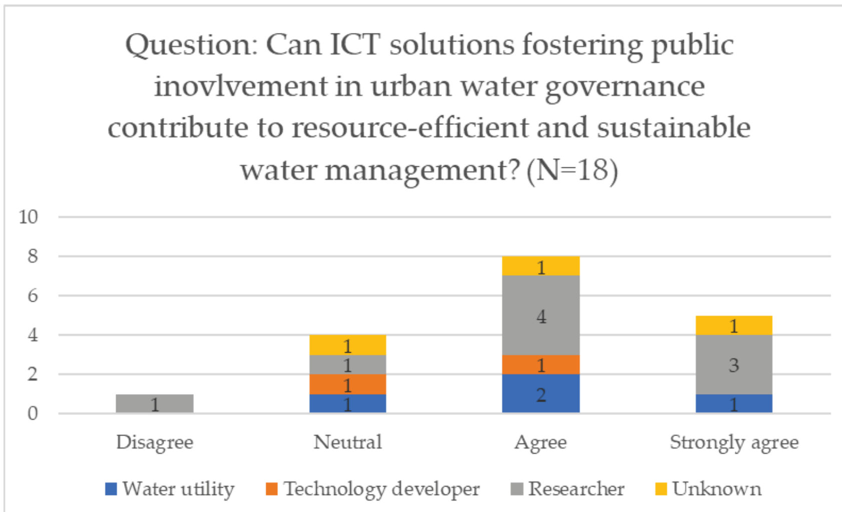

Figure 1. Online survey on assumed contribution of information and communications technology (ICT) solutions fostering public involvement in urban water governance on resource-efficient und sustainable water management across different actor groups conducted within the digital-water city project consortium.

In this paper, we build on two case studies from Berlin, Germany and Paris, France. The two applications in question are (1) an augmented reality (AR) application visualizing groundwater streams in Berlin, and (2) an online application to provide information on the quality of open-water bathing sites on the Seine and Marne rivers in Paris. Through the analysis of these two applications using digital technologies developed within the digital-water city research project, this paper explores the extent to which these solutions can contribute to making two distinct aspects of urban water management—groundwater flows and bathing water quality—visible, and what effects the resulting increased visibility can have on urban water governance and the public discourse around these two issues. Given the limited research in this field, we apply a grounded theory methodology [14] that aims to develop a hypothesis based on empirical observations to be explored in future research.

This paper is thus based on an inductive methodological approach. After providing a review of the relevant literature, we present the methodological framework as well as the co-creational processes that led to the development of the digital applications. We will then apply the methodological framework in the Berlin and Paris case studies and critically discuss the contributions of the digital solutions in making the underlying water management aspects visible and hypothesize in which way the applications may exert influence on the public discourse. The paper concludes by illustrating evidence from the two pilot case studies and giving an outlook on future fields of research.

2. Theoretical Background

An infrastructure is a technical system expanding further than a single site [6]. Its effective functioning for the user tends to mask all the work necessary to maintain it [15]. Technical water infrastructure, in particular, is hidden underground and provides services to end-users without their involvement at any stage of the provision process. Scholars in Science and Technology Studies (STS) have demonstrated the link between the invisibility of infrastructure and the lack of public debate about its development and functioning [16]. An infrastructure only becomes visible "upon breakdown" [6]. Yet, specific programs and "mediating technologies" can foster "the active consciousness whereby users are purposefully engaged in the performance of the network" [16]. Based on these observations, we consider urban water infrastructures as socio-technical infrastructures which comprise not only technical elements but also social interactions such as information exchange [17].

Advances in data-driven urban water management [18] and in digital solutions that can be used independent of time and location can increase the visibility of issues related to urban water infrastructure. Furlong [16] has documented the aspiration of many infrastructure managers towards more visibility. She considers that this could help municipalities to engage in the shaping of the system to better meet population needs. Such an engagement in the shaping of infrastructure requires not only top-down information about the system, but also bottom-up feedback from the population. Are digital solutions "mediating technologies" that can foster such dialogue? Or are they the vehicle for mere top-down information reducing public participation to the lowest degree of citizen participation—that of being informed [19]? Wilcox [20] has argued that the information-giving stance is essentially a 'take it or leave it' approach. Consultation, on the other hand, would include both information-giving and feedback. Making a joint decision would be a subsequent level in which people accept the ideas of their peers, and then choose from the options developed together. We assume that openness to public feedback is not an intrinsic characteristic of digital solutions but depends on their design.

Stein et al. [21] suggest that the effectiveness of digital solutions strongly depends on trust between the different actors involved. In this context, public awareness aims first to increase understanding and acceptance of digital solutions and second to improve the legitimacy and transparency of decision-making. To effectively communicate the benefits of digital solutions, they must be explained to the user in comprehensive clarity and depth. Complex data must be translated into a language that piques the public's interest and motivates laypeople, staff from public administration, and other societal actors to engage in dialogue with scientists and water managers. So far, there is only little knowledge on the effect of the governance settings on the environmental, economic, and societal impacts of such tools [21]. While initial research suggests raised awareness among citizens as a key benefit, others have pointed towards societal and environmental challenges, as well as to effectiveness issues of tools to enhance participation [22]. Scholars documenting participation in planning processes warn against a disproportionate influence of elite and special interest groups in public meetings [23,24]. This tends to distort and hinder attempts to democratize and open up inclusion in decision-making processes, especially in combination with unequally distributed knowledge on specific topics, time availability, and accessibility to meeting sites.

3. Methodological Framework

Applying a mixed-methods approach, we analyze and compare two urban case studies: (1) an augmented reality (AR) mobile application to visualize and raise awareness of groundwater flows in Berlin and (2) a public online application that provides information on bathing water quality in Paris (see Table 1 for a description of the digital solution developed in each case study). We conduct a relational comparison of two case studies in which digital solutions were developed to make these two different water management aspects visible. The comparison is relational [25] as the two case studies have influenced each other through frequent exchanges between the respective water management and developer communities throughout the creation of the applications.

Table 1. Characteristics of the digital solutions in the two case studies (modified from Bouleau et al. [26]).

Features of the Digital Solutions	Berlin	Paris
Background	The tool was developed to make the invisible drinking water exploration infrastructure in Berlin visible	The tool was developed in order to initiate public bathing in the river Seine for the 2024 Olympic Summer Games in Paris
Description of the ICT solution	An augmented reality (AR) app visualizing geology and groundwater and highlighting their relevance as drinking water resources	(1) A smartphone or web application informing the public on the status of the bathing site (2) A web platform informing bathing site managers of water quality
Technology used	OBJ 3D models from MODFLOW dataMODFLOW simulations of scenes	Statistical modeling, machine learning; app not yet decided
Partner involved	Vragments, Berlin Water Works (BWB), Kompetenzzentrum Wasser Berlin (KWB)	Syndicat interdépartemental pour l'assainissement de l'agglomération parisienne (SIAAP), Sorbonne University (SU), KWB
Communication Target Group	General public (e.g., teachers, pupils from secondary school upwards, students); no experts	General public (anyone who might be interested in the bathing app: residents, boat owners); bathing site managers, authorities
User Group	Expert communicators and environmental educators, e.g., at water utilities (BWB or partner utilities) and authorities or non-governmental organizations who conduct guided tours or participate in further training for teachers	Bathing site managers
Aim	(1) Provide information on drinking water sources in Berlin (2) Explain where drinking water comes from and how it gets into wells, and is cleaned during infiltration	(1) Provide information on bathing authorization and additional information on sites (access, affluence, algae...) (2) Provide information on fecal water contamination
Implementation	Off-site	Two different versions to address accessibility and complexity

In order to analyze the governance settings relevant in each case study, we draw on STS as well as on a governance assessment framework developed by Knoblauch et al. [27]. We look more specifically at the research work in the field of STS that has focused on infrastructure. This work sheds light on infrastructure by treating it "relationally", acknowledging that is made of "a bundle of heterogeneous things" (...) "—which involves both organizational work as well as technology" [6,28]. We base our analysis on a grounded theory methodology [14]. Grounded theory, which inherently builds on an inductive approach, is suitable in research contexts where there is limited knowledge and previous research. Given the limited research on digital solutions that aim at making specific urban water management aspects visible, we develop a hypothesis based on our empirical observations in the two case studies to be explored in future research.

The Invisibility of water infrastructure makes it difficult for the public to directly observe and understand the sustainability stakes that the infrastructure may raise. Indeed, such infrastructure supports water withdrawals or water discharge, which are sometimes harmful to the environment, and such impacts may affect people (pollution, restriction on water availability). Since the 19th century, the functioning of urban water networks has directly affected the environment due to their withdrawals in rivers and aquifers (particularly for drinking water production) and discharges (for rainwater and treated water). Despite large investments in wastewater treatment plants, some wastewater is discharged directly into the environment from the combined sewer system during intense rainfall. Groundwater overdraft threatens the sustainable and equitable use of water. Exposing this otherwise largely hidden mode of functioning to the public, which is increasingly sensitive to the protection of the environment, could increase public demands for infrastructure to evolve towards greater sustainability.

Building on Bressers et al. [29,30], the framework by Knoblauch et al. [19] allows for a holistic assessment of the potential of digital solutions for awareness-raising and public involvement in urban water management. It focuses on identifying and assessing non-technical factors relevant for the successful uptake and implementation of information and communications technology (ICT) solutions in urban water management. It is also designed to ensure comparability in analyzing water governance systems between different case studies [29,30]. It identifies interlinked dimensions which can foster or hamper the uptake of water-related digital solutions. After applying this framework in the two case studies, modifications to the governance dimensions analyzed were made, resulting in the framework shown in Figure 2. For each of these governance dimensions, we evaluated four so-called governance quality elements, namely scope, coherence, flexibility, and intensity. In addition, we assessed the general governance context for each dimension to capture general characteristics in the case study.

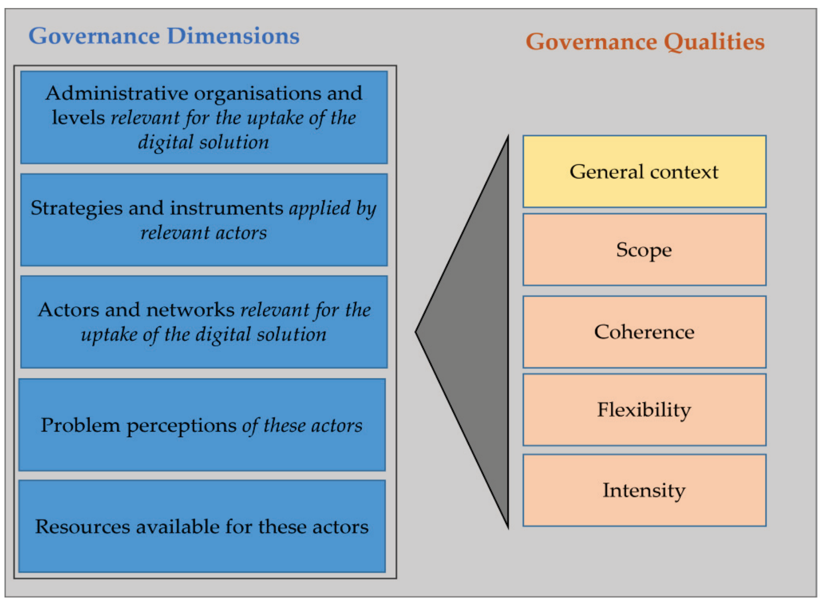

Figure 2. Simplified figure of the Governance Assessment Framework (own figure modified from Knoblauch et al. [27] building on Bressers et al. [29,30]).

To gather precise information, we defined guiding questions for each dimension of the governance structure as proposed by Knoblauch et al. [27]. The guiding questions of the framework structured the analysis of each of the five dimensions along the four criteria of the governance qualities. The guiding questions can best be understood as a starting point for the assessment of individual cases and were adapted to the specific contexts of each case study. An example is provided in Table 2 for the governance dimension "Problem Perceptions".

Table 2. Governance quality criteria for the dimension "Problem Perceptions" (Knoblauch et al. [27] building on Bressers et al. [29,30]).

Governance Quality Criteria	Guiding Questions
Context	• Are different perceptions present in the debate on the uptake of the digital solution? Which are they? And why?
Extent	• How similar/different is the goal associated with the uptake of the digital solution from the status quo? • To what extent do views/arguments/positions support each other, and to what extent are they in competition?
Coherence	• To what extent do actors engage in reframing narratives? Under what circumstances? • Are compromises made in the process of innovation uptake? Why (not)? • Are potential users and their perspectives involved in developing and evaluating digital solutions? Why (not)? • Have there been unforeseen events that have changed the process of the uptake of digital solutions? • Does new knowledge of the system (e.g., ecological, social, economic) play a role in enabling uptake? • To what extent have narratives, power, and regulatory frameworks changed during uptake?
Flexibility	• To what extent does one/several perspective(s) dominate the process of uptake? And why? • Is innovation uptake a primary concern for both users and developers? Why or why not?
Intensity	• How similar/different is the goal associated with the uptake of the digital solution from the status quo?

In each case study, on-the-ground qualitative research was conducted through focus groups and semi-structured interviews with relevant stakeholders (see Table 3) based on the guiding questions developed for each dimension. Initial interviewees were selected based on theoretical sampling (i.e., based on a mapping of actors preidentified by the researchers) in line with grounded theory [14]. Subsequent interview partners were identified through snowball sampling, i.e., by asking the initial interviewers for additional relevant interview contacts.

Table 3. Interviews, focus groups, and Community of Practice meetings conducted (modified from Bouleau et al. [31]).

	Berlin	Paris
Interviews	• Berliner Wasserbetriebe (Berlin Water Utility): scientific staff member and tour guides • Museum guide for future innovations • Senate Department for the Environment, Urban Mobility, Consumer Protection and Climate Action • Expert of environmental engineering firm	• ICT developer: SIAAP • Sanitary authorities in Paris region: Health Regional Agency • Bathing site promoters: Syndicat Marne Vive, Conseil Départemental du Val de Marne, Ville de Paris
Focus Groups	1. Target group: Berlin senate staff, guides, BWB communication staff, September 2021 2. Target group: schoolchildren, July 2022	1. Target group: young bathers, boat-owners, date: May 2021 2. Target group: riparian associations November 2021 3. Target group: bathers and riparians April 2022
Communities of Practice	4. Meetings: September 2019, February 2020, November 2020, October 2021	5. meetings: November 2021, December 2021, January 2022, February 2022, one planned in March 2022.

The material gathered in the focus groups and interviews was systematically attributed to the dimensions of the governance framework. This data assessment process resulted in a state of "saturation", in which additional interviews only supplemented the perceptions and representations already collected in previous interviews [26]. Based on a systematic analysis of the material collected, storylines were developed with consideration of additional literature relevant to each case study. This included both scientific and grey literature, such as policy papers and official regulatory documents.

Both applications in Table 2 are likely to expose specific features of the local water infrastructure that are not well known to the public. In Berlin, the drinking water supply is mainly based on local groundwater resources. A rising demand for water due to the increasing population of the metropolitan area is likely to increase pressure on the water supply [32]. At the same time, interviews conducted by the authors with Berlin water works tour guides indicate that public awareness of the city's drinking water supply is limited, posing challenges to the sustainable use of water resources. In Paris, the possible closure of bathing sites due to poor bacteriological water quality (the criterion considered for health monitoring by the authorities) highlights the occurrence of wastewater discharges during intense rainy episodes in areas with a combined sewer system. The functioning of the sanitation system is poorly known and arouses little interest among the inhabitants (this concerns water, more generally, with a population that is hardly inclined to "participate" [33]. The areas with a separate network (the greater outskirts of Paris) are exposed to wastewater discharges as well, due to ignored misconnections at various levels of the sewerage system. More critically, several tens of thousands of homes (collective or private) are poorly connected (with wastewater flowing into the rainwater, and ultimately into the watercourse). Correcting this problem requires awareness-raising among the population on the subject, and drawing their interest and motivation in the absence of a strong legal constraint to comply [34].

At their core, the two digital solutions are about restructuring and opening up information flows between different stakeholders. While they aim to tackle existing knowledge gaps in a way that differs significantly from previous approaches, they also apply ICT in a new context. The target groups of the app have been defined by the developer teams and validated in the Communities of Practice (CoPs). This resulted in a specification of the target groups over the course of the app development process.

The analysis of these cases aims to shed light on the different dimensions of the governance setting in each case, structured by the guiding questions shown in Table 2. Subsequently, we analyze which part of the public benefits from the digital solution developed.

4. Results and Discussion

In the following section, we describe the results of the analysis of two case studies. The digital solutions developed aim to provide knowledge and raise awareness of (1) groundwater flows in the case of Berlin and (2) bathing water quality in the case of Paris. Both digital solutions are purely aimed at educating and informing and not at participation.

Table 4 below summarizes the findings of Knoblauch et al. [26] and Bouleau et al. [30] for each dimension of the governance setting.

The central water utility in Berlin is the Berliner Wasserbetriebe (BWB). Increasing the efficiency of the existing infrastructure and minimizing impacts on water bodies, e.g., through cost-effective monitoring tools, interoperable data exchange with stakeholders, automated data processing and visualization are major goals of BWB's integrated water management [30]. The city's water policy framework is largely coherent and comprehensive. In 1957, the first law on water protection, the German Water Management Act (Wasserhaushaltsgesetz), was passed, enshrining the idea of sustainable water management. The 1957 law was implemented at the city level in 2005 with the Berlin Law on Water (Berliner Wassergesetz). The key actor in water policy making is the Department for Environment, Transport and Climate of the Berlin Senate (Senatsverwaltung Umwelt, Mobilität, Verbraucher-und Klimaschutz). The city government of Berlin has passed several policy documents and strategy papers, such as the Berlin Smart City Strategy in 2015 [35] and its consolidated version in 2022 [36] that strengthen digitalization in numerous aspects, including water management. The comprehensive climate plan for the city of Berlin is the 2030 Berlin Energy and Climate Plan (Berliner Energie-und Klimaschutzprogramm 2030) [37]. It calls for smart solutions to be integrated into specific practices to improve adaptation and resilience.

Table 4. Description of relevant governance dimensions in Berlin and Paris.

Dimension	Drinking Water in Berlin	Wastewater in Paris
Administrative organizations and levels relevant for the uptake of the digital solution	High fragmentation of digital water governance at city level; Berlin Water Works as dominant actor; different Senate Departments involved in pushing digitalization strategies	Different public actors involved in wastewater management at regional, departmental, and intermunicipal levels; fragmentation is compensated by existence of strong network of water management practitioners with common professional and technical background
Strategies and instruments applied by relevant actors	Senate strategies to push digitalization at city level in place; strategic framework in place for water management	Existing apps foster user–service interface at national and city level (e.g., healthcare, street cleaning). Public actors develop strategies to digitize water quality monitoring and public awareness of the various aspects of wastewater management
Actors and networks relevant for the uptake of the digital solution	Initially little exchange between relevant actors on digital water governance; CoP perceived as very valuable platform for relevant stakeholders	CoP strengthened the interest and trust between stakeholders in sharing knowledge and data
Problem perceptions of these actors (1) What problem could these tools solve? (2) What challenges exist when introducing these tools?	(1) Little awareness of groundwater issues among general public (2) Technical challenges when developing the AR application; limited funding prevents adding additional features	(1) Poor knowledge of bathing water quality due to lack of relevant public information (2) Revealing the bacteriological pollution of surface waters due to the functioning of water systems could be controversial and raise new claims from public for less pollution from sewage discharges
Resources available for these actors	No sustainable framework to ensure long-term use and maintenance of the digital solution	

In the Paris metropolitan area, responsibilities are spread across different administrative levels and sectors [30]. In the area of wastewater management, there is no single authority formally responsible for coordination between local authorities. This role is partially assumed by the state authorities, which are responsible for the implementation and control of regulations and consider the Syndicat interdépartemental pour l'assainissement de l'agglomération parisienne (SIAAP), the wastewater association of the Paris metropolitan area, as the authoritative actor for the functioning of the wastewater system, although it is not responsible for the operation of the upstream sewerage system. Municipalities are responsible for collecting wastewater and stormwater in small sewer systems that feed into larger infrastructure managed at the supra-municipal level. Department authorities are responsible for wastewater transport, and SIAAP is responsible for the final transport to treatment plants and wastewater treatment. Recent legislation on water policy and management has challenged existing water management structures in the Paris region. Responsibilities for water quality communication have not yet been defined. In the field of wastewater and bathing water quality in Paris, three possibilities for ICT development can be defined [30]. The first is the need for reliable water quality forecasting to optimize the duration of bathing periods. The second is about the provision of information to the public about the condition of the baths and bathing facilities so that they can appreciate the investments made. A third aspect comes from the internal discussion within SIAAP. The public app could also collect observations made by the population to inform those in charge about the concerns of users at the sites.

It becomes apparent that there are major similarities as well as differences along these dimensions in the two cases. In both cases, a high fragmentation of digital water governance is present at the city level. Governance fragmentation is an obstacle due to the cross-cutting nature of digital water governance, which comprises different sectoral administrations, such as water and environmental affairs, digitalization and innovation, as well as infrastructure development and urban planning. In both Paris and Berlin, city administrations have issued strategies to foster digitalization, such as the Smart City Strategy in Berlin which can potentially enable the development and uptake of digital solutions. In Berlin, there is no explicit focus on urban water management within these strategies. Similarly, openness to digital innovations was observed to be weak in the case of Paris in comparison to other sectors. This was, however, at least partially offset by a willingness to share data and the reliance on existing digital models.

In addition to these findings, we observed a timing paradox in both cases. When public involvement is low, people have little knowledge of how they could contribute to urban water management practice and what their stakes are in relevant processes. Yet designing appropriate digital solutions requires end-users to engage in design at the earliest stage possible and to make choices without much knowledge of the broader context. To this end, focus groups with identified potential future users of digital solutions helped determine a design that considers user expectations for information (both for information delivered by technical managers and for information reported by users to managers). The organization of these focus groups also revealed which section of the public felt concerned or excluded by digital solutions, as well as the potential of the digital solutions for informing the public. In Paris, the focus groups brought together people who showed interest in the reintroduction of bathing in urban rivers, either because they lived along the river or because they frequently swam in the river. During the discussions, several people expressed doubts about the future importance of the use of this information tool, referring to their personal experience as "non-digital natives" or to their professional experience of working with a young audience. Many people might look for information through other media instead of downloading and consulting a dedicated application. Nevertheless, this digital tool is seen as an entry point for informing future bathers about the possible risks of bathing in the river. The dangers are much more varied and significant than just exposure to selected instances of bacteriological pollution, especially if bathing practices develop outside authorized and supervised sites. Some focus group participants also emphasized the role those digital solutions could play in disseminating information on the local environment and the poorly understood sanitation system. In Berlin, focus groups were conducted with both water management practitioners and school children. While the focus group with water practitioners helped to improve the user experience, the focus group with school children provided valuable insights into the interaction of another main target group of the app. A high degree of digital literacy among the children was an enabling factor for the use of the app, confirming the importance of digital literacy, which was also observed as a conducive factor in Paris. The playful introduction to groundwater streams in Berlin was positively received by the children and could potentially be integrated in the local school curricula. The CoPs set up in each city have been beneficial to bringing relevant stakeholders together across sectors. In both cases, they strengthened the interest and trust of actors for sharing knowledge and data and were thus key enablers of the uptake of digital solutions.

With regards to making urban water management aspects visible, the Paris application has the potential to influence the public discourse on water quality issues by raising awareness on the issue of wastewater discharges into water bodies.

In Berlin, in turn, the groundwater application does not provide information on the detrimental effects of groundwater over-abstraction for the sustainability of the city's water system, leaving sustainability issues and future predictions unaddressed. For the current application to be successful in raising awareness of water sustainability issues, the application needs to be accompanied by supplementary educational measures, e.g., in schools, thus forming part of a wider educational program on the groundwater-related challenges in Berlin. Without these additional measures and given the limited knowledge of the public about Berlin's drinking water supply, it can only provide a starting point for further applications to be developed that raise awareness on the consequences of over-abstraction and unsustainable use of water resources by industry and households. Based on these empirical observations, we derive the following hypothesis to be further tested in future research:

Hypothesis 1 (H1). *If politicization of a specific aspect in urban water management is high, digital solutions that make this aspect visible can change the problem perception and can have an influence on the public discourse about urban water management itself.*

Figure 3 illustrates the assumed interlinkages between digital solutions that increase the visibility of urban water management aspects. Eventually, a shift in problem perception of a specific water management issue can influence the public discourse, which has the potential to change practices in urban water management. The governance setting has to be taken into account as an important contextual variable that affects the topic-specific problem perceptions and can also be affected by a changing public discourse, i.e., when topic-specific problem perceptions result in a change in general problem perceptions of water governance and management actors on environmental and sustainability issues. Certainly, there are some analogies to how information feedback can also lead to changed water consumption or sustainability patterns [38], but this connection was not part of this research.

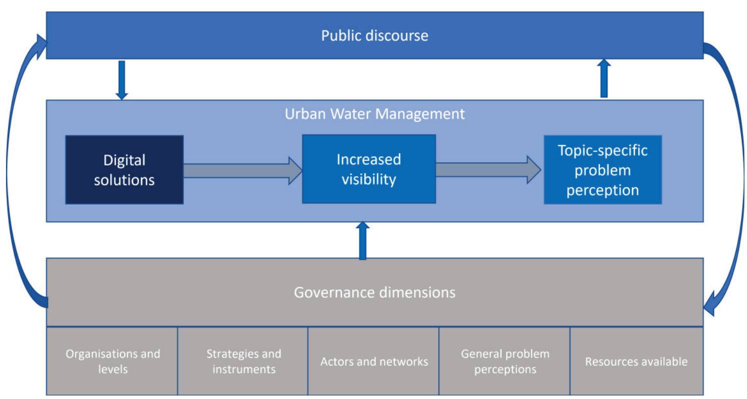

Figure 3. Conceptual diagram based on the hypothesis on the influence of digital solutions for public involvement on the public discourse. The boxes represent the aspects that are discussed in this research, Source: own illustration.

Arguably, the prevalence of traditional, non-digital approaches in urban water management, amongst other factors, points to the challenges that may accompany greater public involvement. Table 5 summarizes some of these hindering factors. Interestingly, many aspects highlight the organizational and institutional challenge that is inextricably linked to the introduction of public involvement solutions.

Table 5. Summarized feedback from stakeholders in urban water management.

Question: What Are the Challenges That May Be Associated with Greater Public Involvement?	Question: What Are the Situations That Must Be Avoided?
• Increased need for water utilities or professional community engagement and moderation • Rising expectations towards water utilities and water managers • Potential conflicting goals/requirements • Explaining complex topics in a simple way needs translation • Representativeness of user feedback is unclear • Potential misalignment between public expectations and available resources • Accountability is not always clear • Potential misalignment between users and decision makers due to communication errors and levels of knowledge	• Decision-making not being in the hands of experts • Confusing users by providing too much data—or, conversely, oversimplifying • Forgetting about the digital non-natives • The processes becoming too complicated when involving the public • Involving the target groups too late • Not being representative • Participation without accompanied education

5. Conclusions

This paper analyzed the conditions under which digital solutions can contribute to making two distinct aspects of urban water management—groundwater flows and bathing water quality—visible, and what effects the resulting increased visibility can have on urban water governance and the public discourse around these two topics.

The digital solutions developed in both cases score low on the ladder of participation [19], as they purely aim to educate and inform the public about groundwater and bathing water quality, respectively [39]. However, in the case of Paris, app users were given the opportunity to provide feedback to bathing site managers, thus going beyond a purely unidirectional stream of information. The current governance conditions, such as a lack of dedicated strategies for digital water services, hinder the development and uptake of digital solutions that go beyond merely raising awareness and sharing information. While the Paris application reveals the problem of wastewater discharges, the Berlin application does not directly show the negative impacts of unsustainable groundwater use. We therefore argue that the potential to change public discourse is limited in Berlin.

The results of the comparative study also show that digital solutions may fail in addressing the needs of all the intended target groups. A reason for this can be an underlying ICT not suitable for certain audiences, such as “digital non-natives” or those who get their information via other means, e.g., social media. Although public interest may facilitate the uptake of the tool, it remains key to communicate the added value of the solutions to the public given the high number of already-existing applications that aim to inform about similar environmental concerns. The analysis underlines the importance of holistic ex ante assessments of the expected societal, ecological, and economic benefits of digital solutions for the respective target groups, to ensure their added value in urban water management. The selection of the right technology is crucial to realize the envisaged benefits. Often, more traditional means of communication, such as educational videos, might be a more cost-effective way of reaching the envisaged target groups compared to digital solutions such as mobile apps. Furthermore, we conclude that digital solutions supporting social awareness should be an integral building block within sustainable urban water management and infrastructure development.

This study has limitations. First, only two cases, which had different foci, were compared. While the Berlin application was developed primarily for information purposes, the Paris application aims not only to inform about bathing water quality, but also to directly trigger a behavioral change regarding water resources. Second, in terms of methodology, it remains difficult to uncover the impact of digital solutions for public involvement based only on data analysis of focus groups, interviews, and documents. Further studies are needed to explore the hypothesis derived in this paper. Future research could also examine whether the developed solutions are able to induce behavioral change. This will require more long-term studies that trace these changes over time.

Generally, the understanding and awareness about water issues is lacking at all governance levels. This partly has to do with water being perceived as a purely technical matter by most actors [21]. Along the lines of Stein et al. [21], we argue that in order to assure adequate acceptance and to promote the benefits of digital solutions, they must be explained to the user in comprehensive clarity and depth. Innovative digital involvement techniques, such as serious gaming, augmented reality, virtual reality, etc., can foster stakeholder engagement, education, and policy communication in the water sector. In this regard, the education sector also plays an important role in raising awareness around water-related challenges, as well as stimulating behavioral change, research, and knowledge-sharing. In our view, digital education could start at a young age, e.g., by better integrating water issues into curricula or training teachers to use digital tools for environmental education. Moreover, research projects should continue to foster the cooperation between administrations, technology developers, utilities, researchers, and citizens to pilot innovative formats. As mentioned above, more user-friendly digital technologies that simplify complex water issues need to be promoted.

To go beyond the mere informative dimension and allow for more in-depth public involvement, for example via a feedback page for technical and administrative staff, the hiring of staff and the designation of a responsible authority will be needed. This could be a much bigger challenge than the development of the application. All in all, more comparative studies are needed, also focusing on those digital solutions that are more likely to allow for active and ongoing user feedback.

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Article

Recognition of Digital Content Needs for Inbound Marketing Solutions

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Abstract: The paper aims to investigate users' behavior regarding inbound marketing while consuming content, in particular, to reveal the source of the reasons and triggers affecting content need in the case of long-consumption products. In the theoretical part of the article, the literature analysis is conducted in order to build a theoretical background. The variety of theories of content values as well as users' decision-making processes are analyzed, and a conceptual view of the origins of content need is formed, which states that the need for a specific type of content emerges under the conditions of the consumer's experienced gap of information or knowledge when in the stages of the buying model. In order to test this hypothesis, empirical research—the survey—was conducted. The main conclusion is that the decision-to-buy model makes a significant impact on the gap experienced by the consumer of the content and has the potential to be used to reveal the need for different content types in terms of its purposes.

Keywords: inbound marketing; content marketing; consumer behavior; web content; digital content; content needs

1. Introduction

Digital solutions for marketing are taking their place with increasing power. There is no doubt as to the necessity to run digital marketing campaigns and activities, but it is about how to make them more efficient and consumer focused. Raising digital marketing concepts, such as inbound marketing and content marketing, causes the scientific issues of understanding consumers' behavior while looking for appropriate content. Such an understanding is crucial for professionals who tend to adopt those two concepts in their companies. Content is the most important element not only in cases of an inbound or content marketing strategy, but also in all cases—social media marketing, email marketing, SEO, etc. It is the reason why a person uses the internet at all. Many sources analyze the phenomenon of digital content marketing, but only a few go deeply into the peculiarities of searching and consuming content in terms of marketing. Many authors state that content should be useful, relevant, and interesting, but there is a lack of knowledge on how the need for a specific type of content arises (Zhang et al. 2021; Štimac et al. 2021; Sun et al. 2022; Davidavičienė et al. 2020, 2021a, 2021b; Hsu and Chen 2018; Hollebeek and Macky 2019). This paper aims to reveal the source of reasons and triggers affecting content needs in the case of long-consumption products.

For the identification of consumer behavior peculiarities, such methods as literature analysis and synthesis were employed. Various theories of content values and user decision-making processes were analyzed, and a theoretical model of content need was formed. This model, which states that the need for a certain type of content emerges under the conditions of the consumer's experienced gap of information or knowledge when in the stages of the buying model were tested after data were collected via a survey. The Cochran Q test and McNemar post hoc test were employed.

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2. Review of Literature

2.1. Content Purpose and Value

Defining digital content, i.e., assessing the purpose of the content, cannot be avoided either for whom or for what purpose it is designed or to meet the content-related needs of users. According to the purpose, the content can be divided into the following categories: (1) educational, (2) informational, and (3) entertaining (de Aguilera-Moyano et al. 2015). This classification of content, which helps to understand what types of content exist, is quite limited from the user's perspective content evaluation, i.e., it does not answer the question of why the consumer will prefer the content of one or another publisher or brand. Additionally, content can match the attributes of several types of content at once, for example, being educational and entertaining at the same time, which in turn makes it difficult to understand how the consumer will react to the content after its consumption, as well as how the consumer's relationship with the brand will be determined in the context of its perception and loyalty. In defining content marketing, it is noted that the content created and distributed must be valuable to the consumer (Hollebeek and Macky 2019; Content Marketing Institute 2020); as additionally (according to Lou and Xie 2021 and based on Schultz 2016; Hutchins and Rodriguez 2018; Ahmad et al. 2016), content marketing contributes significantly to brand development through the delivery of value to consumers, so the purpose of content can also be expressed in terms of value or values to the consumer. Lou and Xie (2021), based on (Ducoffe 1996) the theory of advertising value and (Sheth et al. 1991) the theory of consumption values and aggregating the value perception components of both, presented four value dimensions adapted to digital content—(1) informational, (2) entertainment value, (3) social value, and (4) functional value. They examined the impact of those values on consumer experiential brand appreciation theories and brand loyalty. They suggest defining content values as follows:

The informational value of content is the utility of providing new, timely, helpful, and valuable information about product/brand alternatives in making informed decisions (Ducoffe 1996).

The entertainment content value describes features designed to meet the entertainment needs of users (Ducoffe 1996).

The social value of content describes valuable content that helps to gain social benefits from a social network, such as popularity or similarity.

The functional value of content can capture how branded social media platforms or available media can be a reliable source of information (Ming-Sung Cheng et al. 2009).

By aggregating the value dimensions of different theories, the authors theorize that both the dimensions presented in advertising value theory (informational value and entertainment value) and the consumer value dimension (epistemic, emotional, social, functional, and conditional) can be compared and used to define the digital content value. In order to critically evaluate the results of aggregation and the possibilities of using the presented value dimensions in solving the dissertation problem, it is expedient to analyze in detail the logic of abstraction presented by the authors. Epistemic value, in consumption value theory, is defined as the benefit gained through consumer contact with new information and knowledge during consumption (Sheth et al. 1991). In advertising value theory, informational value is defined as the benefit of advertising in providing new, timely, useful, and valuable information about product/brand alternatives for making informed decisions (Ducoffe 1996). Lou and Xie (2021) assume that these concepts are identical and stick to the concept and definition of informational value. Emotional value refers to feelings or affective states associated with consumption choices (Sheth et al. 1991).

Similarly, the entertainment value of advertising value theory also captures the affective dimension and describes the functions of advertising in meeting consumer entertainment needs (Ducoffe 1996). According to (Sheth et al. 1991), social value defines the benefits of associating alternatives with one or more specific social groups. The addition of (Robertson 1967) the definition of social value—"perceived benefit associated with symbolic or fair consumption (e.g., clothing) or consumption shared with others (e.g., gifts) and often leading to interpersonal communication" concludes that the social value of branded content is defined as valuable content that helps a person obtain social benefits—such as polarity or liking—from their social network. Functional content value is defined as the perceived utility derived from the utilitarian or physical results of consumption choices (Sheth et al. 1991). Lou and Xie (2021) choose to define functional value in the context of their study as a value that can capture how branded social media platforms or managed media can be reliable sources of information (Ming-Sung Cheng et al. 2009). Conditional value, which is defined in consumption value theory as "the perceived utility that an alternative derives from a particular situation or circumstance faced by choice" (Sheth et al. 1991) is rejected by some researchers. They argue that conditional value is more a moderating factor influencing the perception of functional and social values than the independent value dimension (Sweeney and Soutar 2001) or that conditional value is a more special case of the remaining four values than the actual value dimension (Ming-Sung Cheng et al. 2009).

Despite the attractiveness of the value dimensions presented by Lou and Xie (2021) for evaluating digital content, some contradictions in conceptualizing those dimensions can also be seen. Theoretical considerations about the identity of epistemic and informational values are debatable. In a detailed analysis of (Sheth et al. 1991), the concept of epistemic value is observed in two components: "new information and knowledge gained through consumption." Knowledge creation can be understood as a dynamic process in which data are collected and transformed into information that is later transformed into knowledge at different levels of learning (García-Fernández 2015). So, information and knowledge are not the same; rather, information is a means of acquiring knowledge, whereas learning is a prerequisite, as information is transformed into knowledge in the learning process. Information can be interpreted with some knowledge. Information becomes knowledge in the learning process.. Therefore, the epistemic value of the content, in the theory of consumption utility, and the informational value of the content, in the theory of advertising utility, cannot be equated to informational value alone. An equivalent transformation in the context of digital content value and for research purposes can be seen as the breakdown of epistemic value into informational and educational content value. "Relevant content permits you to sell. Content is the driving force behind the engagement effect from partner sites and outposts, content helps to engage in conversations and solve problems on social media, and content is the only way to be visible in search engines" (Chaffey and Smith 2017). Thus, content combines all the elements of inbound marketing into one whole, making content marketing a core activity of inbound marketing. Obviously, without appropriate and relevant content, all the channels used in the organization would be feature-only software. Unfortunately, the concept of relevant and appropriate content remains undefined, leading to the need for both theoretical discussion and empirical research. The relevance and appropriateness of the content to each user may likely be determined by some specific situation and also by the personal characteristics of the user.

2.2. Buying Model

While trying to reveal the triggers of consumer experienced content need, it is worth focusing on users' buying behavior. Recently, researchers have been studying consumer behavior on the Internet from various aspects (Fu et al. 2020; Mishra et al. 2021; Lindh et al. 2020; Dang and Pham 2018; Reyes-Menendez et al. 2020; Wu and Yu 2020). Since the need for the content is assessed in the context of marketing and as a tool for customer satisfaction, we assume that the need for the content arises in the buying process. So, every stage that the consumer passes during that process can provoke demand for the special content.

One of the first purchasing decision-making models dates back to 1910, proposed by J. Dewey (Bruner and Pomazal 1988). This early model consisted of five steps (see Table 1). Subsequently, (Robinson et al. 1967) presented a grid or class model that described three types of purchasing situations: direct repurchase, modified repurchase, and new product purchase. The purchase decision is a process divided into several stages: need recognition, alternative assessment, alternative selection, and finally purchasing decision

(Monat 2009). Following a series of studies, one of the most widely used five-step decision-making models, CDP (consumer decision process) was developed (Kotler and Keller 2016). The model defines user decision making from problem identification (need occurrence) to post-purchase behavior:

(1) Problem recognition;
(2) Information search;
(3) Evaluation of alternatives;
(4) Buying decision;
(5) Behavior after purchase.

Some authors analyzing the process and its application online suggest extending the model to six steps to include an additional "step in the purchasing process" (Chaffey and Ellis-Chadwick 2012). A comparison of the models is given in Table 1. In order to better understand the purchasing process, it is appropriate to analyze all its stages in more detail. Kotler's five-step purchasing model, incorporating the "action" phase proposed by Chaffey, was chosen for a more detailed analysis.

Table 1. Factors affecting decision-making process of virtual teams.

Steps	J. Dewey	Robinson, Faris, Wind	F. Kotler	D. Chaffey
1.	Experienced difficulties	Recognition of need	Recognition of need (problem identification)	Recognition of need (problem identification)
2.	Identification and description of difficulties	Evaluation of alternatives	Search of information	Search of information
3.	Anticipation of possible solutions	Choice of alternative	Evaluation of alternatives	Evaluation of alternatives
4.	Analysis of the consequences	The decision to buy	The decision to buy	The decision to buy
5.	Decision making		After purchasing behavior	Action
6.				After purchasing behavior

Recognition of need (problem identification). The purchasing process begins with identifying the problem when the person realizes an unsatisfactory situation exists. Thus, by identifying the problem simultaneously, the consumer acknowledges the need to address it. Thus, a consumer's purchasing decision is influenced by the problems faced (Jobanputra 2009). Need is the most important factor that drives the purchase of products or services. There are several types of problems: active problems, inactive problems, recognized, and unrecognized.

In practice, revealing and showing problems to consumers is a means of increasing sales when their obvious solutions are offered at the same time. Consumers' efforts to find alternatives depend on various factors: market (number of competitors, brands), product characteristics (importance, quality), consumer characteristics (interest), etc.

Search of information. When a person admits that he or she needs a certain product or service, he or she tries to gather as much information about it as possible. The main task of marketers is to determine which sources of information have the most significant impact on their target market. At this evaluation stage, the customer has to choose between alternatives for brands, products, and services. The user can obtain information from such sources as the following:

- Personal: family, friends, neighbors, and so on.
- Commercial: sellers, advertisers, brokers, etc.
- Public: magazines, radio, newspapers, television, etc.
- Web: social networks, portals, search engines and so on.
- Experience: use, handling, analysis of a product or service.

The search for information may vary depending on the situation (Schoell and Guiltinan 1991). There are three levels of consumer decision making:

- Extended problem solving—a large amount of information is required;
- Limited solution—less information is needed because the consumer has already defined the product evaluation criteria but has not yet decided which alternatives to choose;
- Routine response behavior—a small amount of information is required, as the user experience with the product is already sufficient, and they can easily choose from many alternatives.

Evaluation of alternatives. Three types of assessment of alternatives are important in assessing which alternatives best meet the needs of the user, distinguished by the following:

- Comparative—The person in this state usually focuses on the technical details. They compare offers and choose the one they think is best. The key question at this stage is "is this the best option"?
- Implementation—A person focuses on the day-to-day use of goods or services. Usually, the consumer wants to know, "will this choice improve his daily life"?
- Results oriented—The decision is made only when the consumer is convinced that this choice will help to fulfill his obligations, improve and measure performance, i.e., increase profits or productivity, reduce operating costs, and increase competitive advantage. These people tend to ask themselves, "Will this help me get closer to X"?

In the context of information technology development and information availability, these stages become much more complex, creating new scientific challenges.

The decision to buy. The consumer finally acquires the product or service through the steps listed above.

Meanwhile, Dann and Dann (2011) single out five purchasing decision-making principles:

1. Man is not a perfect decision maker because irrational behavior is easily predictable;
2. When it comes time to make a decision, the consumer is looking for the easiest solution, relying on previous experience;
3. People tend to make decisions as simple as possible, so they usually choose between similar options;
4. The forces of default and complexity have a significant impact on decision making;
5. The results of a decision can often be predicted and influenced.

Action. A well-presented incentive at this stage forces the consumer to "buy now" (Chaffey and Ellis-Chadwick 2012). The purchasing action and its timing are deliberate. The importance of this stage is emphasized in e-commerce.

Post purchasing behavior. After purchasing the product, the consumer undertakes an analysis—whether the decision was made correctly, i.e., whether the product was useful or met the needs and expectations of the user. Riley (Riley and Ungerleider 2012) argues that the post-purchase reaction manifests itself in cognitive dissonance; in judging the decision, the consumer thinks the alternative option would be better.

In summary, it can be said that all steps of buying decision model can trigger the need for content. The question is, what kind of content? At the beginning of the process, when the consumer is unaware of the problem that should be solved, thus there is no need for the product, the consumer will probably consume the entertainment content, which in turn can trigger the need for the product. In the search stage of the information, the consumer will probably look for informational and educational content. At the action stage, consumers can face uncertainties and phobias while using the e-shop, so there could be a focus on, for example, educational content.

3. Research Methodology

In order to identify the link between the consumers' stage of the buying model and the need for a certain kind of content, the survey was conducted (data collection period was September–November 2021). The respondents were asked what type of content they need most while being in the specific stages of the buying decision model. The questionnaire was distributed using social media to random respondents. Three hundred thirty-six questionnaires were appropriately filled. Others were rejected because of various biases. The study was conducted in the context of consumer durables, as such products require deeper consumer involvement and more effort. The research was conducted in Lithuania. No specific industry was singled out in the study. Respondents were asked to imagine any durable relevant to them. It should be emphasized that content format preferences are not studied, nor are content search and consumption channel preferences, but only the content function expressed through the purpose of the content.

The extended 6-step buying decision-making model was employed in the research. It consists of the following steps: problem identification/needs identification, information search, comparison of alternatives, purchase decision, purchase process, and post-purchase behavior. The information retrieval phase was divided into two situations—information retrieval, knowing how to solve a problem, and information retrieval when encountering a problem for which the consumer is unaware of the product. Thus, in the final version, the stages of the purchasing decision were represented by seven situations. Respondents were asked to choose what kind of content is relevant to them (such content they will seek) in these situations. Content purpose categories include informational content (INF), educational content (EDU), entertainment content (PRAM), and interactive content (INT). So, the questionnaire consists of 10 questions. Three of them are intended to identify the demographic structure of the respondents. The seven questions are situations that define the user's being at a specific stage of the purchase decision and the answer options, which consist of content types defined through the purpose of the content.

Hypothesis H1 was formulated: the existence of a statistically significant difference in consumers' need for a particular content purpose (educational, informational, entertaining, and interactive) when the consumer is at a particular stage of purchasing decision (problem identification/need emergence, information retrieval, alternative comparison, purchasing decision acceptance, purchasing process, and post-purchase behavior) (see Figure 1).

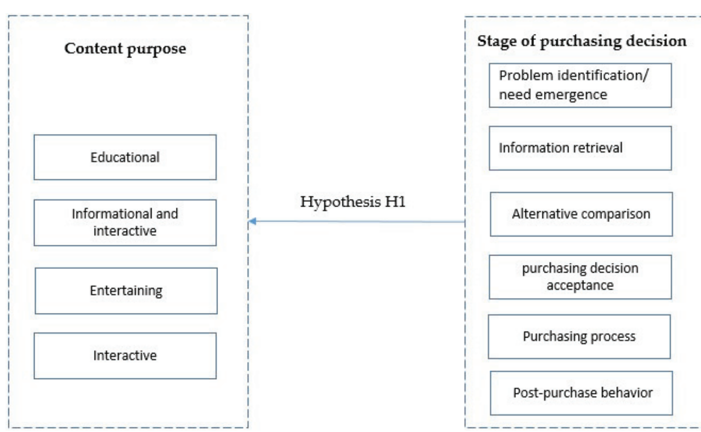

Figure 1. Factors affecting consumer choice of web content.

The demographic data are presented in Table 2. The respondents consist of 21.1% males and 68.8% females. This show some limitations of results, considering that the male population is not represented in full scale.

Table 2. Demographic characteristic respondents.

Details	Percentage
Gender	Male: 21.2 Female: 68.8
Age	>18: 1.5 18–24: 39.3 25–34: 14.6 35–44: 27.1 45–54: 12.2 55–64: 3.6 <65: 1.8
Education	Higher: 60.5 Secondary: 35.6 Profession: 1.5 Basic: 2.4

It can be concluded based on the sample analysis that females were more active and willing to participate in the research than men. It should also be noted that the most active group were those who were most educated (higher education 60.5%). The share distribution in the age category was relatively similar in the main groups (those with the most buying potential and needs).

4. Discussion of Results

While analyzing received data, the need for informational content at all stages is clearly observed (see Figure 2). The least informational content is sought (compared to other stages) in the first stage when the consumer has not yet encountered a situation to be resolved. The need for educational content is clearly expressed in cases where the consumer is faced with a problem, the solution of which does not come from experience (PETA 2), or where it is necessary to learn how to use the products. In the first problem identification stage (PETA1), the consumer moves from a state where they do not understand that there is a problem to be solved by purchasing a particular product, to a state where the consumer understands the problem and takes action to address the problem.

At this stage, the content offered by the organization can help the user understand the problem, but it should be what the user expects. The research results show that the content most used in the problem identification phase is entertaining and the quite intensively used content of an informational and educational nature. The second stage of the purchasing decision model is the search for information divided into two components: when a consumer is faced with a problem where he/she does not know the product and method to solve (PETA2), and when he/she knows from experience the product that needs to be solved (PETA3). In the first case, there is a clear need for both informational and educational content. It should be noted that more respondents indicated educational content as the target at this stage. It is due to the fact that without knowing a specific product or facing a problem for the first time that cannot be solved from experience, the consumer is forced to learn how to solve that problem and what products are designed to solve it. When a consumer immediately recognizes the need to target a specific product, he or she focuses on searching for information about that product, such as technical product specifications, so in this case, the dominant content is informational. From the perspective of inbound marketing solutions for business organizations, this means that in cases where, for example, the product is innovative or non-widespread and unknown to the public, or where an organization’s products or groups of products are designed to address a consumer’s lifecycle, educational content covering the broadest possible range of consumer issues becomes essential. When comparing alternatives, the consumer focuses on informational content that may be dictated by the need to compare the specifications, features, and prices of different products. At this stage, the need for interactive or functional content emerges, i.e., consumers show an intention to look for convenient product comparison solutions. According to the distribution of the need for content, the purchase decision stage is very similar to the stage of comparison of alternatives analyzed earlier (no significant difference between the results is recorded). It can be explained by the assumption that the respondents perceive these two stages in the same way—after all, the decision to buy a particular product is the result of a comparison of alternatives, so the consumer's decision to buy can be treated in the same way as a comparison of alternatives. At the purchasing stage, consumers take active steps to purchase the product for which a decision has been made. By linking the need for content use with this stage, respondents single out the need for educational content alongside information content. At this stage, consumers are likely to face, for example, certain uncertainties and fears related to e-shop functions. This, in turn, forces the consumer to look for content that can help eliminate those uncertainties and teach how to use one feature or another. After purchasing, consumers face cognitive dissonance challenges and challenges related to product operation, so the need for educational content is also evident at this stage, and the need for entertaining content is growing.

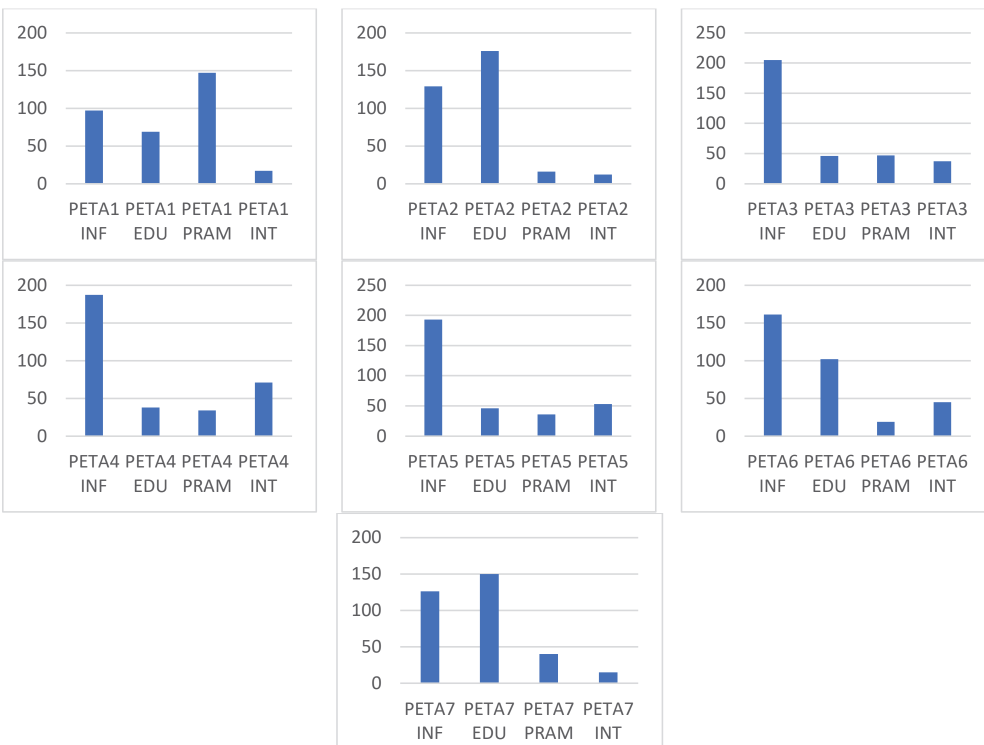

Figure 2. Distribution of preferred by respondents' content in buying model stages.

Hypothesis H1 assesses the existence of a statistically significant difference in consumers' need for a particular content purpose: educational, informational, entertaining, and interactive when the consumers are at a particular stage of their purchasing decision: problem identification/need emergence, information retrieval, alternative comparison, purchasing decision acceptance, purchasing process, and post-purchase behavior. For this purpose, Cochran's Q test is used, with H_0, success rate equal to all study groups, and H_1, a success rate that differs in at least one group. The study found (see Table 3) that at all stages of the purchasing decision, statistically significant differences are recorded in the purpose of the intended content, so H_0 is rejected and H_1 is accepted, confirming H1.

Table 3. The results of Qochran's Q test.

PETA1-7 INF		PETA1-7 EDU		PETA1-7 PRAM		PETA1-7 INT	
N	336	N	336	N	336	N	336
Cochran's Q	131,981	Cochran's Q	288,404	Cochran's Q	298,193	Cochran's Q	97,413
df	6	df	6	df	6	df	6
Asymp. Sig.	0.000	Asymp. Sig.	0.000	Asymp. Sig.	0.000	Asymp. Sig.	0.000

In summary, Hypothesis H1, the presence of consumers at a particular stage of the purchasing decision determines the purpose of the intended content, is confirmed. In the context of inbound marketing, the reasons for users' activity in pursuing one type or another of online content are crucial.

The source of these reasons may be the state of the consumer, in which the consumer seeks or may seek information and knowledge in the form of digital content that confers some of the uncertainties to be addressed. Thus, the extended six-step purchasing decision model essentially explains the origin of volume demand expressed through the content purpose in the context of inbound marketing and can be used to model traffic to a business organization's website, but the insights gained from the study need to be considered. The information retrieval phase must be divided into two components, characterized by situations in which (a) the user identifies a problem in the demand recognition phase for which the solution or measures are not known, and (b) the consumer identifies a problem for which the product needs to be identified, and the need is immediately recognizable. At these stages, differences are observed for all content uses. It should be noted that in the case of the PETA4-PETA5 stages, there is no significant difference in the intensity of the demand for content in all cases (INF, EDU, PRAM, and INT), which means that, as mentioned above, organizations only need to consider the specifics of the alternative comparison phase when creating content to meet the demand for content in the purchasing stages.

5. Conclusions

The analysis of the literature showed that content marketing and thus content itself is an essential element of inbound marketing. The different value theories state that content, just like anything else, has its own value to the consumer, and value has predefined dimensions. This research is based on the assumption that content values defined in the literature are not perceived in that way at the very beginning of a consumer's activity related to content search and consumption but rather are perceived as a purpose of the content. Based on theoretical research, four content purposes that the consumer can perceive were clarified—informational, educational, entertaining, and interactive content.

On the other hand, after analyzing the user's buying decision models, the extended 6-stage model was chosen for the research as explaining the origins of the consumer's need for content.

The empirical research showed that there is a relationship between the consumer's presence in the stages of buying decision model and content purpose, and that model can be employed as a base for the explanation of content need origins in terms of inbound marketing. It should be noted that some insights should be considered: (1) The information search stage must be divided into two considering different situations, the one where the consumer faces a problem that cannot be solved based on the past experience of the consumer and where the consumer knows what product solves the recognized problem. (2) The test applied in this research reveals significant differences when comparing different situations all at once. It does not compare the need for different content types in pairs of stages of buying model, so additional research and analysis of the data are needed.

A limitation of the study is that the study was conducted in the context of consumer durables without identifying a specific industry. This determines the need to expand research by narrowing the context in the sense of specifying the industry.

For further research and a more detailed scope and understanding of the web content needs, it is necessary to study the factors that determine the need for specific content at each stage of the purchase decision, as well as areas of interest of consumers that impact the demand for certain content.

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Relationship Recognition between Knowledge and Ability Based on the Modularity of Complex Networks

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Abstract: The purpose of formal education is to increase students' abilities, and its content is to impart knowledge through various courses. Thus, it is essential to accurately identify the relationship between knowledge and students' ability increment to ensure the quality of education and the sustainable development of education. Currently, this relationship is mainly established based on previous educational data and teachers' experience, which is often imprecise. This paper proposes a framework for knowledge and ability recognition based on the structural characteristics of complex network modules. The proposed framework utilizes a knowledge cognitive-interdependent network model (KCIN) as its object. First, the key knowledge nodes are identified via cognitive convergence flow of knowledge nodes in KCIN. Subsequently, the module structure of the knowledge network is identified by taking the key knowledge nodes as the core. Finally, the relationship between knowledge and ability is established by identifying the similar attributes of nodes in complex network modules. To validate the framework, we use teaching process data on the Data Structure course, which is a fundamental course for Information majors. The results show that the framework can effectively optimize the knowledge–ability relationship acquired from previous data and teacher experience.

Keywords: knowledge; ability; relationship recognition; complex networks; modularity; educational sustainability

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1. Introduction

1.1. Knowledge and Ability

The relationship between knowledge and ability has been an enduring topic and a classic problem [1]. The acquisition of knowledge and the addition of competence both constrain and reinforce each other. According to the philosopher Locke, man is able to acquire knowledge from sensory experiential material because he possesses a certain number of native abilities, such as memory, attention, comparison, observation, and abstraction [2]. Bruner, who is the representative of structuralism, argued that the purpose and task of teaching should not focus solely on enabling students to master the necessary knowledge and skills, and should develop their abilities as well. He believed that proficiency in knowledge structure could lead to an increased ability to use knowledge effectively, emphasizing the importance of knowledge structure and meaningful connections between knowledge [3]. Xing et al. have suggested that, from the viewpoint of performance and development of ability, knowledge is formed and developed in part through the process of mastering skills; from the viewpoint of the counteraction of ability to knowledge and skills, a certain ability is necessary for attaining further mastery of both knowledge and skills. This implies that ability is both the premise of mastering knowledge and the result of mastering knowledge, and as such there is both a mutual dependency and interdependence [4]. Wang et al. proposed that knowledge is the basis of ability development, intelligence is the crystallization of knowledge, development of ability can improve the speed and quality of knowledge mastery, and the goal of ability is the premise of converting knowledge into ability [5].

Li et al. viewed competency as an organized knowledge system and linked the relevant knowledge scattered in various courses and chapters into a network system. They argued that the problem of competency is fundamentally a problem of knowledge, and that its solution requires a detailed and in-depth study of knowledge [6]. In summary, knowledge and ability are closely related. This paper mainly investigates the supportive relationship between knowledge and ability in formal education, such as the relationship between the KMP algorithm and EPSA in the data structure course, which indicates that learning KMP algorithm knowledge can enhance students' engineering problem design ability.

1.2. Knowledge Graph and Ability Enhancement

The identification of the relationship between knowledge and ability requires the expression of knowledge relations and the evaluation of capability enhancement. According to Wang Xiaoming and other scholars, knowledge is the subjective representation of people on objective things and laws, while ability signifies the personal psychological characteristics that promote completing activities smoothly and achieving the desired purpose. Knowledge is divided into conceptual knowledge and procedural knowledge. Conceptual knowledge is reflected in "understanding (or not) what and how", while procedural knowledge is reflected in "how to do"; skill is reflected in "can (or not) do"; finally, ability is reflected in "can solve, can do, can finish". Knowledge is the basis of ability. The deeper the understanding of knowledge and the firmer the mastery of it, the more skillful the corresponding skill is, which is conducive to the improvement of ability [7]. Yang Dingsheng believe that knowledge and ability are not one-to-one correspondences. The formation of one ability may require the interaction of multiple areas of knowledge, while multiple abilities may require the same knowledge. The relationship between knowledge and ability can be divided into two aspects: first, knowledge learning is the basis of ability appreciation, as without a certain amount of knowledge to support, it is impossible to produce good ability appreciation; second, ability appreciation is the ultimate goal of knowledge learning, as without ability appreciation knowledge is only be a set of simple memories [8].

As a visual tool for scientific knowledge, knowledge graphs [9] can effectively help students to identify the relationship between knowledge points. Using the knowledge graph approach, it is possible to effectively integrate fragmented knowledge on the subject, helping students to master the subject systematically. In this way, we can understand the changing and developing situation of the field of knowledge in order to effectively improve students' learning efficiency [10–13]. Bernal first invented the subject map in 1939, and Ellingham used manually drawn charts to show the relationship between subjects in 1948 [14]. Knowledge graphs are essentially a kind of knowledge base called semantic networks, that is, a knowledge base with a directed graph structure. The nodes of the graph represent entities or concepts, and the edges of the graph represent various semantic relationships between entities or concepts [15]. Ding Guofu built a fine knowledge point map and ability point map for each teaching link, studied the integration mapping relationship between knowledge points and ability points, constructed a teaching system based on knowledge and ability integration evaluation, recorded the knowledge point map and ability point map of students' life cycle education, and tracked it throughout the process, enabling the teaching effect to be evaluated, tracked, analyzed, and improved [16]. Petri-Net builds a knowledge map, then uses students' learning history to predict their learning effect when studying future concepts in the future and maximize their learning results [17].

Value-Added Assessment is a developmental evaluation model which mainly adopts quantitative evaluation methods [18]. It evaluates the educational effectiveness of students by quantifying the increase in their learning abilities during the learning process [19]. This assessment method combines the advantages of predictive, formative, and summative evaluation, with the learner's original ability level as the "initial value", the ability level at a certain stage of the learning process as the "current value", and the ability level after the end of the learning process as the "final value", dividing the evaluation process into three parts [20]. This method is increasingly being recognized by schools all over the world. British scholars first systematically introduced the implementation of value-added assessment in their country in 1998 and the system showed good system stability, which attracted the reference of other countries such as the Netherlands [21]. Many states in the United States have developed and applied value-added assessment systems, including the Tennessee Value-Added Assessment System and Dallas Value-Added Assessment System [22].

1.3. Research Problem

In the process of continuous knowledge teaching, schools need to realize the gradual improvement of students' abilities [23]. In this process, it is necessary to accurately recognize the relationship between knowledge and capability, which is a key link in achieving sustainable development in education as well [24]. However, this relationship is not a specific and clear quantitative relationship; rather, it is a fuzzy and generalized qualitative relationship [25]. Even within the same course,the relationship between knowledge and ability may be different due to the differences in the teachers and students involved, and potentially even very different. The relationship between knowledge and ability is usually based on the course divisions according to the learning order and the content proximity of knowledge points. The increment of ability is mainly evaluated through the score values of all the corresponding knowledge points. Adopting this approach to obtain the knowledge and ability relationship ignores the mutual influence between knowledge points. In order to make up for the inadequacies of qualitative identification methods for knowledge and ability relations based on experience, this paper proposes a knowledge and ability relation recognition framework based on the module feature of the knowledge relation network model. According to the cognitive dimension, the knowledge-dependent network model is constructed, then the key knowledge nodes are identified based on the network structure feature. Taking the key knowledge nodes as the core, the network module structure is identified and the corresponding relationship between the knowledge module and ability is established to realize the recognition of knowledge and ability relations.

2. Materials and Methods

2.1. KCIN Construction

Learning cognitive views and constructivist perspectives suggest that the achievement of a specific learning goal is based on a cognitive process of certain knowledge [26]. In order to recognize the relationship between knowledge and ability, we construct a KCIN based on the course knowledge graph of a course [27] according to the dimension of cognitive process, which serves as the foundation for recognizing the relationship between knowledge and ability. The nodes in the KCIN are the course knowledge points, and the edges are the relationships between knowledge nodes. The extraction of course knowledge points mainly relies on the teacher's experience. First, the course content is determined according to the location and role of the course in the cultivation program, then the course content is gradually constructed into a tree-shaped course knowledge point graph. The knowledge points that serve as the leaf nodes are the nodes of the KCIN. There is no fixed requirement for the number of nodes, and certain nodes are connected by edges. Whether there is an edge between two nodes is determined by the knowledge content they represent. If node A must be studied before node B is studied, there exists an edge from B to A, and the weight of the edge is the degree of influence of B's content on learning A, which is divided into five levels corresponding to 0.5, 0.4, 0.3, 0.2, and 0.1, respectively.

Referring to the common characteristics of the knowledge dimension and cognitive process dimension expressed by Bloom's Cognitive Structure Learning Theory [28–30], we divide the network nodes into conceptual knowledge nodes and procedural knowledge nodes and the cognitive process dimension into the understanding application dimension and analysis evaluation dimension, separately constructing an understanding and application knowledge network (UAKN) and an analysis and evaluation knowledge network (AEKN). The relationship between our taxonomy and Bloom's taxonomy is shown in Figure 1. The three cognitive process dimensions of Bloom (remember, understand, and apply) are equivalent to the understanding analysis dimension in this paper, while the three cognitive process dimensions (analyse, evaluate, and create) are equivalent to our analysis evaluation dimension. Moreover, Bloom's factual and conceptual knowledge are equivalent to our conceptual knowledge, and Bloom's procedural and metacognitive knowledge are equivalent to our procedural knowledge.

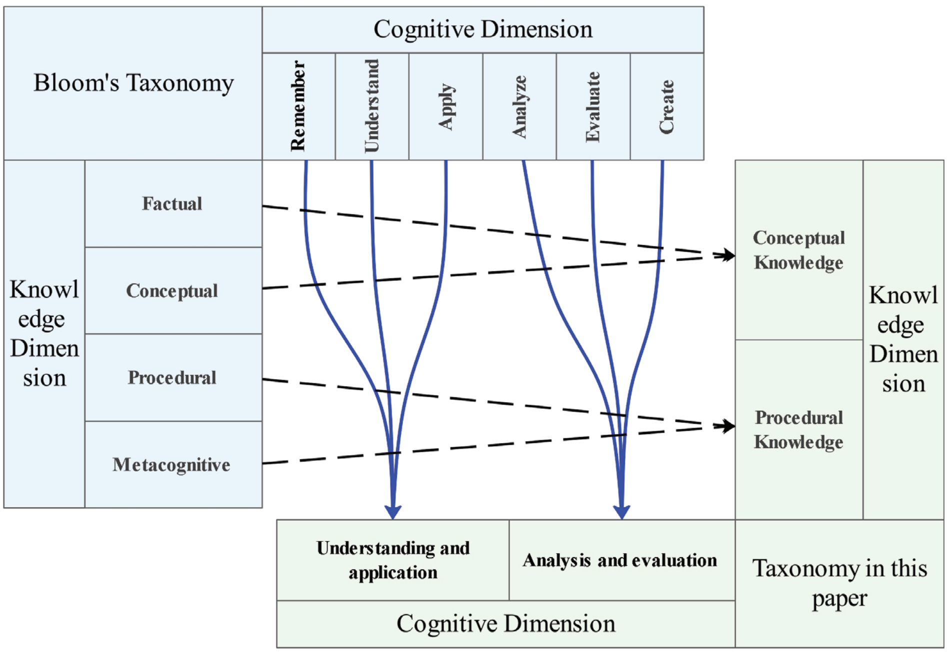

Figure 1. The relationship between Bloom's Taxonomy and the taxonomy proposed in this paper. The light blue part is Bloom's Taxonomy, with the four knowledge dimensions (factual, conceptual, procedural, and metacognitive) listed vertically. The cognitive process dimensions (remember, understand, apply, analyze, evaluate and create) are listed horizontally. The green part is our taxonomy, with two knowledge dimensions, namely, Conceptual and Procedural Knowledge, listed vertically and two cognitive process dimensions (understanding–analysis and analysis–evaluation) listed horizontally. The dashed lines in the figure show the mapping relations between the two taxonomies in terms of knowledge dimensions, while the solid lines show the relations in terms of the cognitive process dimensions.

In UNKN, "understanding" refers to comprehending meaning, then transforming, rewriting, and explaining issues; as such, it refers to learners' ability to express questions in their own language. The application of UNKN refers to learners being able to apply the concepts they have learned to new situations or use their learned knowledge in other scenarios [31]. The edges in UNKN represent the supporting relationships between different conceptual knowledge nodes as well as the support relationships between conceptual knowledge nodes and procedural knowledge nodes, which have directions; the starting nodes are conceptual knowledge nodes, while the terminal nodes are either conceptual or procedural knowledge nodes. Analysis in AEKN refers to decomposing a learning target into its components and determining how they are related to each other in order to understand the original target. Evaluation in AEKN refers to students being able to evaluate the value of certain viewpoints according to certain evaluation criteria [31]. The edges in AEKN represent the support relationships between different procedural knowledge nodes and the support relationships between procedural knowledge nodes and conceptual knowledge nodes, which have directions; both the starting nodes and terminal nodes are procedural knowledge nodes. Finally, the KCIN is constructed based on the correspondence and connections between the same nodes in the UNKN and AEKN.

2.2. Recognition of Key Knowledge Nodes

Based on the structural characteristics of KCIN [32–34] and the basic equation of information science proposed by Belkin [35,36], we extract the flow-in tree of each node i in UNKN and AENK. The flow-in tree is a tree-like structure with node i as the root node that contains all the incoming path nodes connected to it and all the edges in the tree pointing from lower-level nodes to higher-level nodes. We identify the key conceptual and procedural knowledge nodes by taking the root node keyness in the flow-in tree as the criterion for judging the importance of the node.

The key degree μ_i calculation equation of root node i is

$$\mu_i = \sum_{j\in\omega, i\neq j} \sum_{k\in j\rightarrow i} l_k(\theta) \tag{1}$$

where ω is the leaf node of the inflow tree extracted with i as the root node and $l_k(\theta)$ is the weight of edge k in the path from node j to node i.

2.3. KCIN Module Identification

The relationship between knowledge and ability is a one-to-many relationship, where the enhancement of each ability requires the support of many knowledge points. Modularity is an important attribute generally possessed by complex networks, and the connections between nodes within a module are relatively dense, the connections between modules are relatively sparse, and nodes in the same module often have similar properties [37,38]. In order to identify the modular structure of the KCIN, we first merged the two nodes connected by the dependent edge into one node, then utilized the spectral clustering method to recognize the merged network [39]. The idea of the spectral clustering algorithm is derived from graph partition theory, which regards the clustering problem as a multi-way partition problem of an undirected graph. As KCIN is a directed weighted network, it can better exploit the characteristics of the spectral clustering algorithm. We tried other clustering methods such as hierarchical clustering; however, the clustering results were not as good as spectral clustering. The main idea of the spectral clustering algorithm is to extract the features of objects using the normalized random walk Laplacian matrix proposed by Shi and Malik [40], then to infer the structural relationship between the objects using the extracted features.

The main process is as follows:

1. The radius search method or nearest neighbor method is used to define a local neighborhood for each node, then the bidirectional distance $Dist_{i,j}$ of all points i and j in the neighborhood is calculated.
2. The bidirectional distance $Dist_{i,j}$ is converted into a similarity measure by kernel transformation, as shown in Equation (2):

$$S_{i,j} = \exp(-(\frac{Dist_{i,j}}{\sigma})^2) \tag{2}$$

   where the matrix S is the similarity matrix and σ is the scale factor of the kernel.
3. The non-normalized Laplacian matrix is calculated and either the random walk Laplacian matrix or the symmetric Laplacian matrix is normalized.
4. A matrix V is created with k columns, where the columns are k eigenvectors corresponding to the k minimum eigenvalues of the Laplacian matrix.

5. Each row of matrix V is regarded as a node, which are clustered by the k-means or k-medioids clustering methods.
6. Knowledge nodes are assigned to the same cluster as their corresponding rows in matrix V.

2.4. Relationship Determination and Ability Quantification

The main goal of this paper is to propose a framework for identifying the set of knowledge points with the highest correlation to a certain ability among many knowledge points. Since the main goal of course teaching is to cultivate students' abilities through the learning of knowledge; the most important purpose of determining the relationship between knowledge and ability is to use it as a basis for quantitative evaluation of abilities, and the accuracy of ability quantification is an effective criterion for verifying recognition results as well. In order to make the ability quantification simple and feasible, we propose an ability quantification method based on the assessment results of the knowledge points provided by the teacher in the learning process. The abilities supported by knowledge learning are derived from the syllabus. We determine the relationship between knowledge points and abilities based on the key knowledge points and module recognition results of KCIN. First, according to the instructor's understanding of the course objectives and teaching experience, a one-to-one support relationship is established between the key knowledge points with the highest importance and the abilities that are most relevant to the target. In this way, each ability corresponds to a key knowledge point. Then, according to the module recognition results of the knowledge points, a one-to-many support relationship is established between all the knowledge nodes in the module in which the key knowledge points have been associated with abilities and the target of the ability. The process is shown in Figure 2.

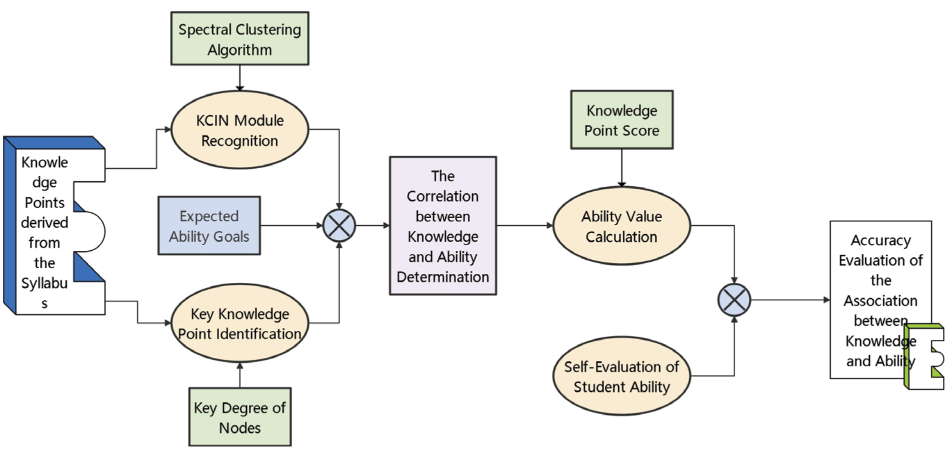

Figure 2. The process of recognition and accuracy evaluation of the relationship between knowledge and ability.

According to the relationship between knowledge node and ability, we can calculate ϕ_x, which is the increment of ability x, as shown in Equation (3):

$$\phi_x = \sum_{p,y \in module_x} \left[\alpha \langle \varphi_y \mid \varphi_p \rangle + (1-\alpha) \langle \gamma_y \mid \gamma_p \rangle \right] \tag{3}$$

where $module_x$ represents all knowledge nodes in the module corresponding to ability x, α is a weighting parameter which mainly serves to differentiate the support of knowledge points to different cognitive dimensions in terms of their ability to achieve the desired objectives. Teachers should set this parameter according to the specific ability.

The degree of conceptual knowledge nodes y for cognitive dimensions of understanding and application φ_y, as shown in Equation (4):

$$\varphi_y = V(y)(1 - \sum_{\overleftarrow{y}_c \in input_y} \eta(\overleftarrow{y}_c)) + \sum_{\overleftarrow{y}_c \in input_y} \left[\eta(\overleftarrow{y}_c)\varphi_{\overleftarrow{y}_c}\right] \quad (4)$$

The degree of conceptual knowledge nodes y for cognitive dimensions of analysis and evaluation γ_y is shown by Equation (5):

$$\gamma_y = \sum_{\overleftarrow{y}_c \in input_y} \left[\eta(\overleftarrow{y}_c)\varphi_{\overleftarrow{y}_c}\right] \quad (5)$$

where $\overleftarrow{y}_c$ is the preordered node of knowledge node y, $\eta(\overleftarrow{y}_c)$ is the weight of the edge with node c pointing to point y, $input_y$ is the preordered node set of node y, and $V(y)$ is the fraction of knowledge node y.

The degree of conceptual knowledge nodes p for cognitive dimensions of understanding and application φ_p is shown by Equation (6):

$$\varphi_p = \sum_{\overleftarrow{p}_g \in input_p} \left[\eta(\overleftarrow{p}_g)\gamma_{\overleftarrow{p}_g}\right] \quad (6)$$

The degree of conceptual knowledge nodes p for cognitive dimensions of analysis and evaluation γ_p is shown in Equation (7):

$$\gamma_p = V(p)(1 - \sum_{\overleftarrow{p}_g \in input_p} \eta(\overleftarrow{p}_g)) + \sum_{\overleftarrow{p}_g \in input_p} \left[\eta(\overleftarrow{p}_g)\gamma_{\overleftarrow{p}_g}\right] \quad (7)$$

where $\overleftarrow{p}_g$ is the preordered node of knowledge node p, $\eta(\overleftarrow{p}_g)$ is the weight of the edge with node g pointing to point p, $input_p$ is the preordered node set of node p, and $V(p)$ is the fraction of knowledge node p.

2.5. Data for Validation

In order to verify the effectiveness of this framework, we applied it to a course on Data Structure. This framework can be used for all courses, and can be used for various professional talent cultivation systems as well, without any restriction in terms of the course type. The reason why we chose a Data Structure course to validate the effectiveness is that we teach this course at Beihua University, meaning that we were able to collect complete teaching process data and obtain consent of the 114 registered students to use their learning process data for research. The Data Structure course involves teaching students the theoretical foundations of programming. We collected and analyzed the syllabus for the Data Structure course from ten universities, as shown in Table 1, and extracted 42 knowledge points based on the syllabus of Beihua University, including 24 conceptual knowledge points and 18 programming knowledge points, as shown in Table 2. The syllabus included clear teaching knowledge points, ability cultivation objectives, and the relationship between knowledge and ability. The teaching knowledge points were derived from the knowledge content involved in program design using data structure, the ability cultivation objectives were derived from the overall objectives of the student training scheme, and the knowledge and ability relationship was extracted based on the subjective experience of teachers and experts in the field. The relationship between the knowledge and abilities identified by this framework was then compared with that of the knowledge and abilities in the syllabus.

Table 1. Course outlines of different Data Structure courses.

University	Source Website
Loyola Marymount University	https://cs.lmu.edu/~ray/classes/dsa/syllabus/, accessed on 1 November 2022
Chongqing University	http://www.cse.cqu.edu.cn/info/2105/3558.htm, accessed on 1 November 2022
Rutgers University	https://ds.cs.rutgers.edu/, accessed on 1 November 2022
Chengdu University of Technology	https://www.icourse163.org/spoc/course/CDLGDX-1466089245, accessed on 1 November 2022
Johns Hopkins University	https://www.cs.jhu.edu/~hager/Teaching/cs226/index.html, accessed on 1 November 2022
Shanxi Normal University	https://jwcweb.sxnu.edu.cn/info/1242/5542.htm, accessed on 1 November 2022
Liaoning University of Technology	https://seie.lnut.edu.cn/info/14452/185005.htm, accessed on 1 November 2022
Gujarat Technological University	https://www.studocu.com/in/document/gujarat-technological-university/computer-science/3130702-data-structures-syllabus/6180222, accessed on 1 November 2022
Massachusetts Institute of Technology	https://ocw.mit.edu/courses/6-851-advanced-data-structures-spring-2012/pages/syllabus/, accessed on 1 November 2022
Beihua University	https://eie.beihua.edu.cn/, accessed on 1 November 2022

Table 2. Knowledge units of Data Structure course.

No.	The Name of Conceptual Knowledge	No.	The Name of Procedural Knowledge
1	Classification of data structures	25	Applications of linear list
2	Abstract data types	26	Four arithmetic operations
3	Complexity of algorithm	27	Recursion of the stack
4	Sequence list	28	Naive matching algorithm
5	Slist	29	KMP algorithm
6	Doubly linked list	30	Traversing binary tree
7	Cyclic linked list	31	Minimum spanning tree
8	Sequential Stack	32	Shortest path algorithm
9	Link stack	33	Traversing graph
10	Sequential queue	34	Critical path
11	Linked queue	35	Linear look-up table
12	Sequential string	36	Tree based look-up
13	Linked List	37	Hash method look-up
14	Storage of arrays	38	Insertion sort
15	Sparse matrix	39	Exchange sort
16	General List	40	Selection sort
17	Tree definition and storage	41	Distributive sort
18	Sequential storage of binary trees	42	External sort
19	Linked storage of binary trees	-	-
20	Hoffman tree	-	-
21	Graph definition and storage	-	-
22	B-tree	-	-
23	Keyword tree	-	-

3. Results

3.1. KCIN of the Data Structure Course

Based on the method introduced in Section 2.1 and the data in Section 2.5, we constructed the KCIN of the Data Structure course as shown in Figures 3–5. The square nodes represent the understanding–application dimension of the knowledge points, while the circular nodes represent the analysis–evaluation dimension of the knowledge points. Figure 3 is the KCIN of the course, Figure 4 is the AEKN in the KCIN of the course, and Figure 5 is the UAKN in the KCIN of the course. The direction of the edges in UAKN and AEKN is from the precedential knowledge points to the subsequential knowledge points, while the weight of the edges is the support degree from the precedential knowledge points to the subsequential knowledge points. The precedential knowledge points refer to the knowledge points of a more basic nature which need to be learned prior to the subsequential knowledge points. The interdependent edges between UAKN and AEKN have no direction or weight, and connect the same knowledge points between the two cognitive dimensions.

Using the Pajek software [41], we calculated the basic structural characteristics of AEKN and UAKN, as shown in Table 3. The in-degree of UAKN is 29.13% that of AEKN, the out-degree is 2.79 times that of AEKN, the clustering coefficient [42] is two times that of AEKN, and the betweenness centrality [43] is similar. The in-degree measures the amount of prerequisite knowledge required in the learning process, the out-degree measures the support of the learned knowledge for subsequent learning, the clustering coefficient measures the closeness of the relationship between knowledge points, and the betweenness centrality measures the necessity of learning knowledge points. Compared with AEKN, UAKN has less in-degree and more out-degree, indicating that UAKN is better able to express the characteristic relations of the basic cognitive dimension of the knowledge points, which is in line with the understanding and application dimension characteristics. The higher clustering coefficient of UAKN compared to AEKN indicates that the relationship between knowledge points in the understanding and application dimensions is closer. From the cognitive point of view, understanding and application is the basis of analysis and evaluation, and the structure of the basic cognitive stage is closer to the characteristics of cognition. These network characteristics further confirm the accuracy of our network model.

Table 3. Topological features of KCIN for the Data Structure course.

Network Name	Network Input Degree Centralization	Network Output Degree Centralization	Watts-Strogatz Clustering Coefficient	Network Transitivity Clustering Coefficient	Network Betweenness Centralization
UAKN	0.07138608	0.59607377	0.24907444	0.13625402	0.01685009
AEKN	0.24509221	0.22010708	0.12371543	0.10207940	0.01598751

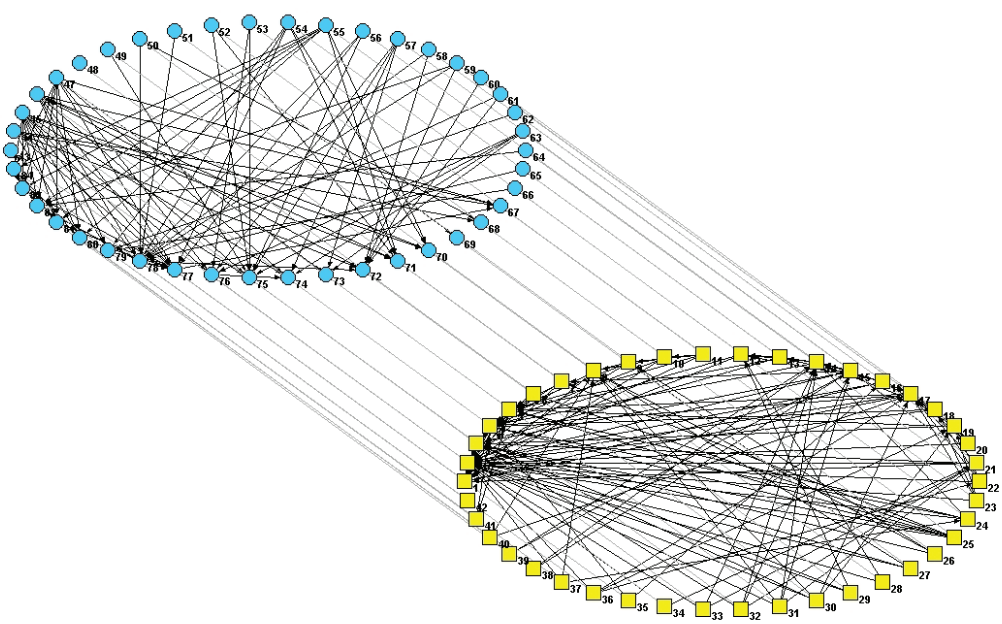

Figure 3. KCIN of the Data Structure course. The figure was drawn with Pajek. The serial numbers of the nodes come from Table 2, and the gray edges are the dependent edges of AEKN and UAKN.

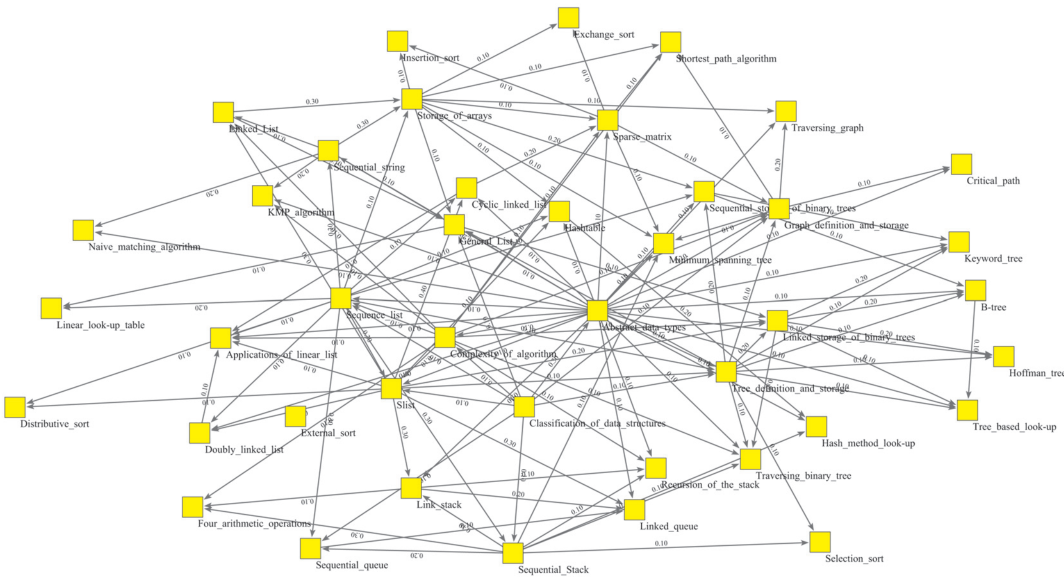

Figure 4. UAKN in KCIN.The figure was drawn with Pajek. The mark of the square node is the knowledge name, and the mark of the edge is its weight. Whether there is an edge between two nodes is determined by the understanding and application dimensions of the knowledge points they represent. If node A must be studied before node B is studied, there exists an edge from B to A where the weight of the edge is the degree of influence of B's content on learning A, which is divided into five levels corresponding to 0.5, 0.4, 0.3, 0.2, and 0.1.

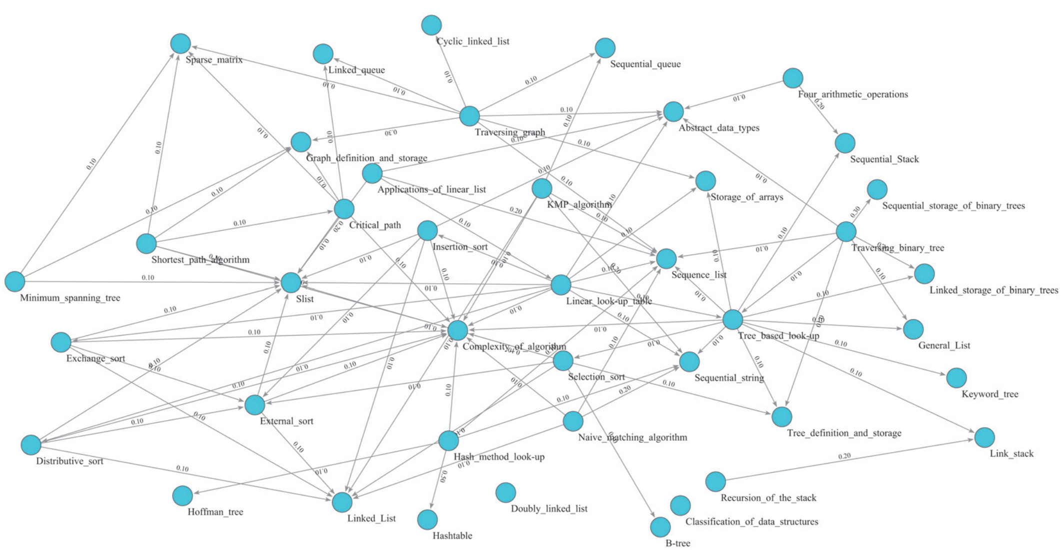

Figure 5. AEKN in KCIN. The figure was drawn with Pajek. The mark of the circular node is the knowledge name, while the mark of the edge is its weight. Whether there is an edge between two nodes is determined by the analysis and evaluation dimension of the knowledge points represented by these two nodes. If node A must be studied before node B is studied, there exists an edge from B to A where the weight of the edge is the degree of influence of B's content on learning A, which is divided into five levels corresponding to 0.5, 0.4, 0.3, 0.2, and 0.1.

3.2. The Supporting Relationship of Knowledge and Ability

3.2.1. Extracting Ability Objectives for the Course

As an engineering course, the training goal of Data Structure course is mainly based on international general engineering certification standards. Based on the ability objectives of the syllabus of Beihua University, we referred to the syllabi of other nine universities, as mentioned in in Section 2.5 and Table 1, and extracted five engineering abilities that the course supports: Advanced Programming Language Application Ability (APLA), Engineering Problem Expression Ability (EPEA), Complex System Mathematical Model Building Ability (CSMA), Engineering Problem Solution Design Ability (EPSA), and Data Analysis and Processing Ability (DAPA). There are differences in the ability development objectives among different universities, which mainly derive from the schools' orientation and their students' foundations. As the performance data of 114 course-choosing students in Beihua University were the basic data used for evaluation in this paper, we considered it more reasonable to take the ability objectives in the teaching syllabus of Beihua University as the main basis. The different cognition dimensions of knowledge have different support relationships with different abilities. The support relationship between the cognitive dimensions of knowledge and engineering abilities with respect to the Data Structure course is shown in Table 4.

Table 4. Support parameter for abilities.

Ability	Understanding Application Dimension	Analytical Evaluation Dimension	α Value in Equation (3)
APLA	100%	0%	1
EPEA	100%	0%	1
CSMA	50%	50%	0.5
EPSA	30%	70%	0.3
DAPA	10%	90%	0.1

3.2.2. Identification of Key Knowledge Nodes

We identified the key knowledge nodes among the 42 knowledge nodes in the Data Structure course according to the method described in Section 2.2. Because there were a total of five competencies supported by this course, we extracted the five knowledge nodes with the largest weights, as shown in Table 5. The five key knowledge nodes for understanding the application dimension are tree-based look-up, minimum spanning tree, B-tree, keyword tree, and traversing binary tree, while the five key knowledge nodes for the analytical evaluation dimension are the complexity of the algorithm, S-list, linked list, sequence list, and external sort.

Table 5. Key knowledge nodes.

Name (Analytical Evaluation Dimension)	Value (Analytical Evaluation Dimension)	Name (Understanding Application Dimension)	Value (Understanding Application Dimension)
Slist	2.3	Tree based look-up	6.2
Linked List	1.8	Minimum spanning tree	6
Sequence list	1.2	B-tree	5.8
External sort	1.1	Keyword tree	5.8
Sequential string	1	Traversing binary tree	5.6

3.2.3. Module Identification

All nodes in the network module identified based on the feature recognition of the network module were taken as the supporting knowledge nodes of the ability. In order to identify the module structure in KCIN, we merged the two dependent nodes into one node to obtain the combined network of UAKN and AEKN according to the dependence relationship of the nodes in KCIN. Then, the module structure of KCIN in the Data Structure course was identified according to the spectral clustering method introduced in Section 2.3. We set the number of modules according to the number of key knowledge nodes and used continuously clustering until each key knowledge node belonged to a different module; that is, each identified module contained only one key knowledge node. Finally, modules containing key nodes of different dimensions were mapped to separate subnets of corresponding cognitive dimensions. Because knowledge nodes of the understanding application dimension support five abilities, we identified five knowledge modules based on five key knowledge nodes of UAKN, then took the knowledge nodes of these five modules as supporting knowledge nodes of APLA, EPEA, CSMA, EPSA, and DAPA, as shown in Figure 6. Similarly, as the knowledge nodes of the analysis and evaluation dimension support three abilities, we identified three knowledge modules according to the three key points of AEKN and took the knowledge nodes of these three modules as the supporting knowledge nodes of CSMA, EPSA, and DAPA, as shown in Figure 7.

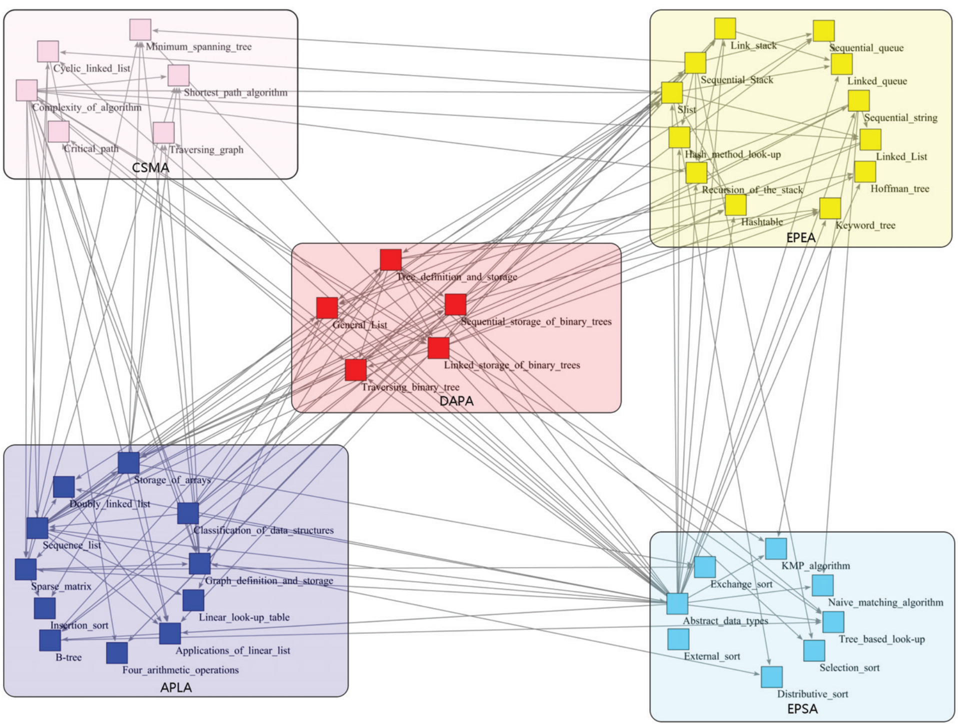

Figure 6. The results of the UAKN module identification are divided into five modules. The supporting knowledge nodes of EPEA include SList, Sequential Stack, Link Stack, Sequential Queue, Linked Queue, Hoffman Tree, Keyword Tree, Hashtable, Recursion of the Stack, and Hash Method Look-up. The supporting knowledge nodes of EPSA include Abstract Data Types, Naive Matching Algorithm, KMP Algorithm, Tree-based Look-up, Exchange Sort, Selection Sort, Distributive Sort, and External Sort. The supporting knowledge nodes of DAPA include General List, Tree Definition and Storage, Sequential Storage of Binary Trees, Linked Storage of Binary Trees, and Traversing Binary Trees. The supporting knowledge nodes of APLA include Classification of Data Structures, Sequence List, Doubly Linked List, Storage of Arrays, Sparse Matrix, Graph Definition and Storage, B-Tree, Applications of Linear List, Four Arithmetic Operations, Linear Look-up Table, and Insertion Sort. The supporting knowledge nodes of CSMA include Complexity of Algorithm, Cyclic Linked List, Minimum Spanning Tree, Shortest Path Algorithm, Traversing Graph, and Critical Path.

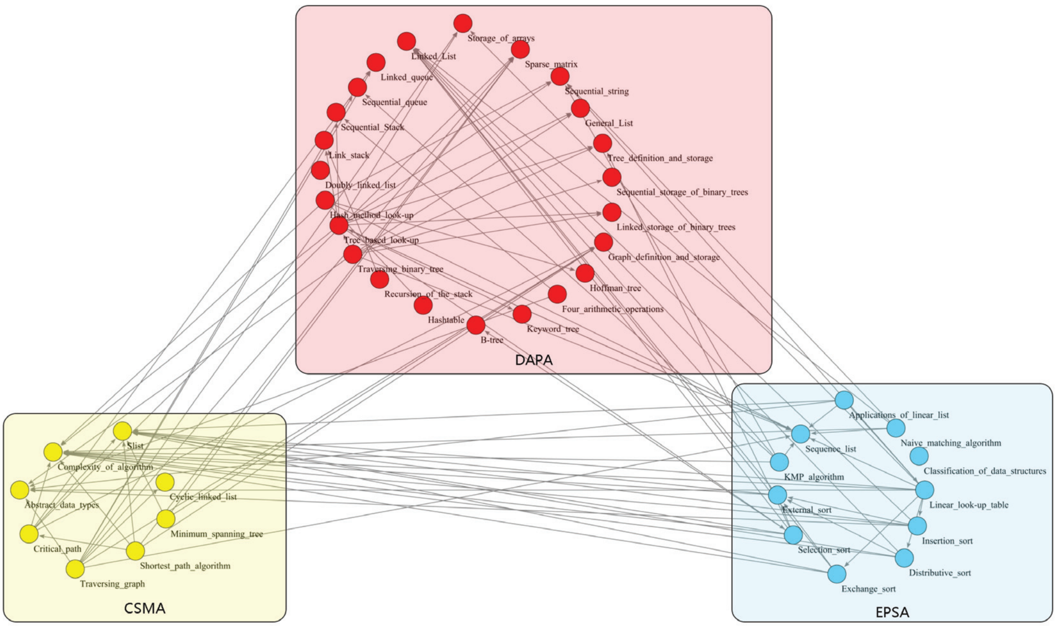

Figure 7. Module identification results of AEKN. It is divided into three modules. The supporting knowledge nodes of CSMA include Abstract Data Types, Complexity of Algorithm, S-list, Cyclic Linked List, Minimum Spanning Tree, Shortest Path Algorithm, Traversing Graph, and Critical Path. The supporting knowledge nodes of EPSA include Classification of Data Structures, Sequence List, Applications of Linear List, Naive Matching Algorithm, KMP Algorithm, Linear Look-up Table, Insertion Sort, Exchange Sort, Selection Sort, Distributive Sort, and External Sort. The supporting knowledge nodes of DAPA include Doubly-Linked List, Sequential Stack, Link Stack, Sequential Queue, Linked Queue, Sequential String, Linked List, Storage of Arrays, Sparse Matrix, General List, Tree Definition and Storage, Sequential Storage of Binary Trees, Storage of Arrays, Sparse Matrix, General List, Tree Definition and Storage, Sequential Storage of Binary Trees, Linked Storage of Binary Trees, Hoffman Tree, Graph Definition and Storage, B-tree, Keyword Tree, Hash Table, Linked Storage of Binary Trees, Hoffman Tree, Graph Definition and Storage, B-tree, Keyword Tree, Hash Table, Four Arithmetic Operations, Recursion of the Stack, Traversing Binary Tree, Tree-based Look-up, and Hash Method Look-up.

4. Discussion

In order to validate the effectiveness of the knowledge and ability relationship recognition framework proposed in this paper, we used the knowledge and capability relationship identified by this framework in the Data Structures course introduced in Section 3.2. Then, based on the identified relationships and knowledge scores, the five ability values of each of the 114 students who enrolled in this course at Beihua University were calculated. Finally, the calculated ability values, ability values obtained from the traditional association relationship, and self-evaluation results of the 114 students' abilities were compared. The knowledge scores were the scores of the various tests designed by the teacher that the 114 students performed during the learning process. The traditional knowledge and ability association relationships were taken from the corresponding relationships between the knowledge points and the ability goals in the syllabus, which were set by the teacher according to experience, and the ability values were the average of all the associated knowledge scores.

We verified the effectiveness of the recognition framework by examining the results. If the framework can effectively identify the relationship between knowledge and skills, all the knowledge points of a certain major can be merged into a set, and the relationship between knowledge points and skill objectives can be recognized through the framework. This helps to overcome teachers' limited cognition of different courses, and at the same time can avoid excessive learning of knowledge with the same ability improvement effect, which is favorable for the sustainable development of education. The method used to verify the effectiveness of the framework was to compare the recognition results, the results of grading evaluation, and the self-evaluation results of the students. The closer the recognition results of the framework are to the self-evaluation results of the students compared to the grading evaluation results, the more effective the framework.

4.1. Analysis of Ability Value Distribution

The ability values were calculated according to the calculation method introduced in Section 2.4 and the relationship between knowledge points and abilities identified in Section 3.2, and the parameter α was set according to Table 4. The maximum value of the ability is the ability value when all the knowledge points are full marks. In order to facilitate measurement and comparison, we normalized the ability values and set the maximum value of the ability to ten points. The distribution of the five abilities of the 114 students is shown in Figure 8A, and the trend of the ability values of all students is shown in Figure 8B. From the figure, it can be seen that the distribution trend of the five abilities of all students is basically the same, and the size of the five abilities of each student is different, while the trend of the ability values relative to other students is the same. This phenomenon is in line with the general law of students' ability enhancement, that is, although the range of individual abilities of the students is different, the range of abilities of good students is generally superior [44].

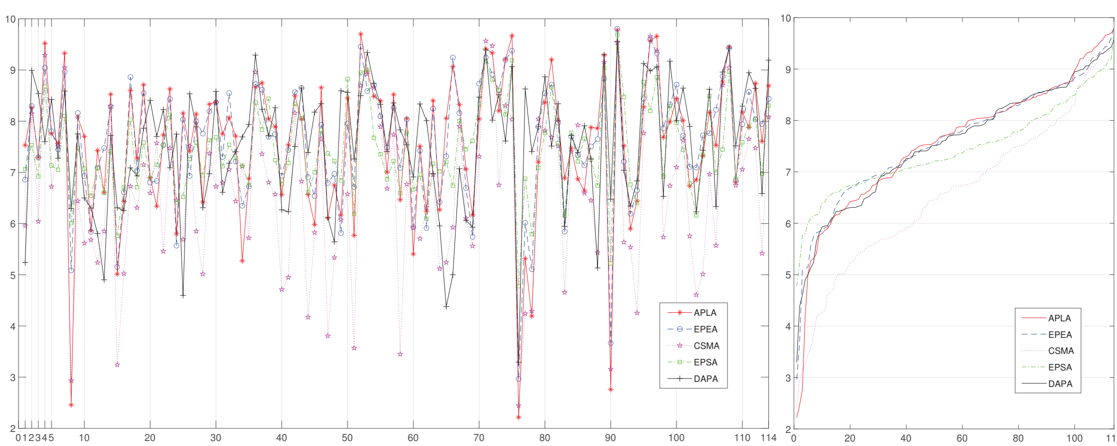

Figure 8. The distribution of five abilities of the 114 students. The X-coordinate in (**A**) represents the student's serial number, and the Y-coordinate represents the normalized ability value. Each X-coordinate value has five Y-coordinate values corresponding to it, with the shape of asterisk, circle, pentagram, square, and plus sign in the figure representing APLA, EPEA, CSMA, EPSA, and DAPA, respectively. The X-coordinate in (**B**) represents the ranking of values of abilities, with each ability ranked in ascending order. The Y-coordinate represents the values of students' abilities. The curves coloring red, blue, purple, green, and black represent the trends of APLA, EPEA, CSMA, EPSA, and DAPA respectively.

4.2. Ability Value Comparison Analysis

According to the correlation of knowledge points and abilities in the syllabus of Section 2.5, we associated knowledge and abilities. Then, based on the correlation, we calculated the ability values in the traditional way, which is to average all the corresponding knowledge point scores. The distribution of the five abilities values of 114 students calculated by this framework and in the traditional way are shown in Figure 9A–E, respectively. We calculated the correlation coefficients of the ability value distribution of the same ability item for two different modes [45] in order to measure the difference between the two in terms of the knowledge and ability relationship. The correlation coefficients of the calculation results of the five ability values of the 114 students using the two modes are shown in Figure 9F, which are 0.835, 0.838, 0.584, 0.763, and 0.760, respectively. It can be seen that the evaluation results of the two methods on APLA and EPEA are similar, while the evaluation results on CSMA, EPSA, and DAPA are quite different.

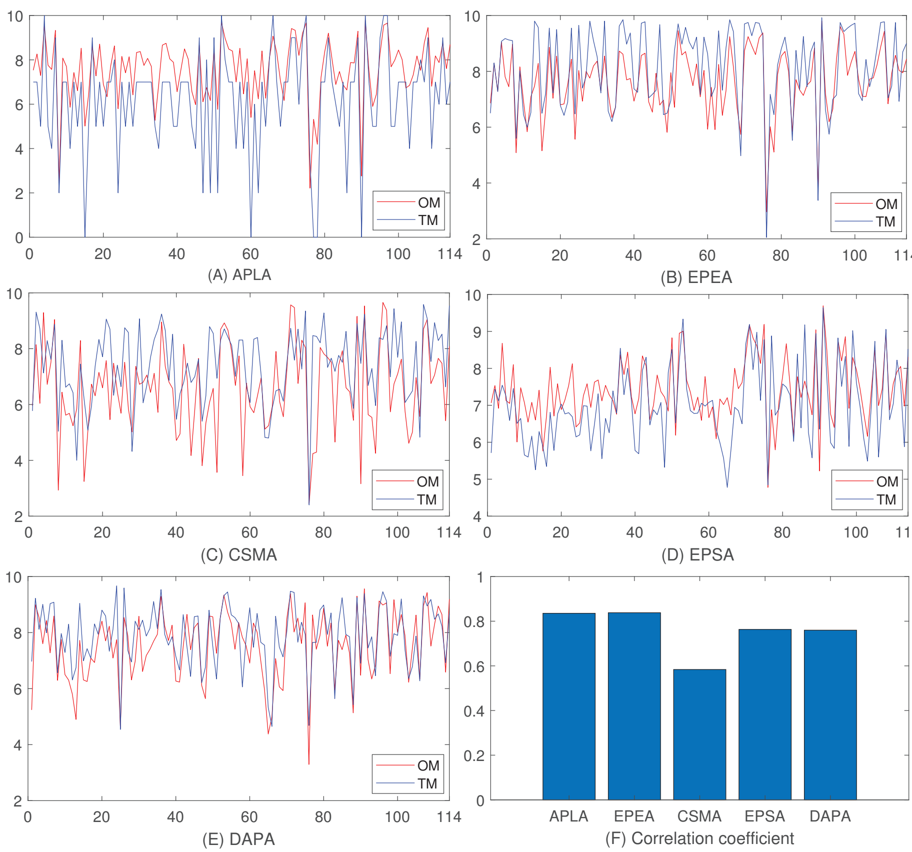

Figure 9. Distribution of the five abilities of the 114 students. OM represents the result distribution curve of our mode and TM represents the result distribution curve of traditional mode. (**A**–**E**) show the distribution of APLA, EPEA, CSMA, EPSA, and DAPA of the 114 students, respectively. Here, "our mode" refers to the ability value calculated based on the relation between the knowledge and ability identified by the framework presented in this paper, while "traditional mode" refers to the ability value calculated based on the relation between the knowledge and ability obtained from the teacher's experience in teaching the syllabus.

4.3. Analysis of Accuracy of Knowledge and Ability Relationship Recognition

Based on the discussion in Section 4.2, the ability values calculated by the relationship between knowledge and ability obtained by this framework are significantly different from those calculated by the relationship between knowledge and ability in the syllabus. To verify which one of the two results is more accurate, we compared the two ability values with the ability results evaluated by the students themselves. The main content of the questionnaire was the achievement of APLA, EPEA, CSMA, EPSA, and DAPA, for example, "ability to analyze the characteristics of practice problems, added-value achievement evaluation", "ability to identify key links in complex problems, added-value achievement evaluation", etc. The answers were divided into five levels: complete agreement (10 points), good agreement (8 points), agreement (6 points), basically agreement (4 points), and non-agreement (2 points). The reliability and validity [46] of the questionnaire are shown in Table 6. The results for Cronbach's Alpha [47], Eigenvalues, Cumulative % of Variance [48], KMO [49], Bartlett's Test of Sphericity [50], and df show that the survey is valid.

Table 6. The reliability and validity of the questionnaire.

Cronbach's Alpha	Eigenvalue	Cumulative % of Variance	KMO	Bartlett's Test of Sphericity	df
0.994	19.61	89.14%	0.955	4450.123	231.000

Through the survey questionnaire, we calculated the average self-evaluation values of five abilities for the 114 students. Then, we compared and analyzed the average values of the five abilities obtained from the knowledge and ability relation calculation in the framework of this paper with those from the knowledge and ability relation calculation in the syllabus and the self-evaluation values of 91 students for five ability increments. As shown in Figure 10, the trend of the five abilities curve obtained from the framework of this paper is very similar to that of the ability increments from the self-evaluation, with a correlation coefficient of 0.9079. The change trend of five ability values obtained from the support relation in the syllabus is significantly different from that of the ability values from the self-evaluation, with a correlation coefficient of −0.0233. Thus, it can be proven that the proposed knowledge–ability relation recognition framework can optimize the knowledge and ability relationship previously set by teachers' experience.

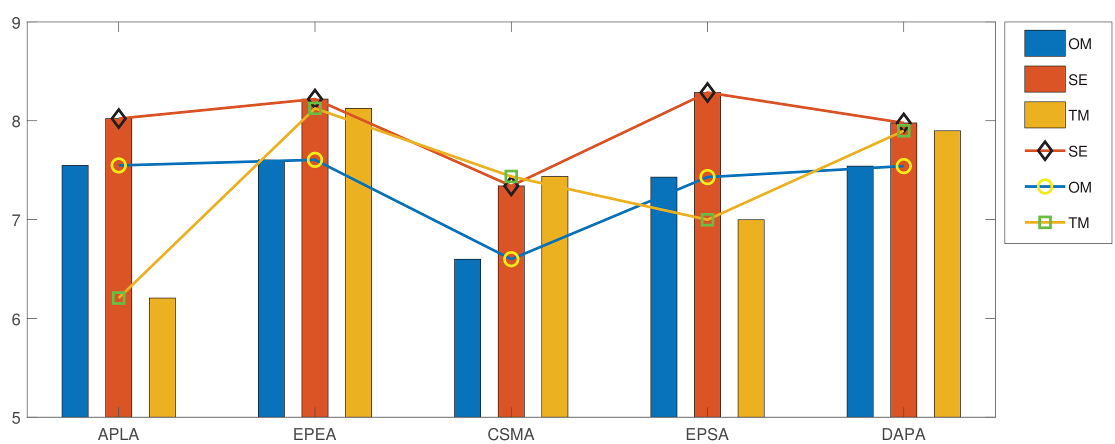

Figure 10. Comparison of the evaluation results of abilities. OM, SE, and TM in the figure are the ability values obtained by our method, student self-assessment, and the traditional method, respectively, while OMT, SET, and TMT are the trend curves of the abilities obtained by above methods.

5. Conclusions

The enhancement of students' abilities is an essential link in sustainable development in education; universities in particular need to play a key role in R&D as well as in knowledge production and dissemination. To achieve the transition to a low-carbon and resource-saving economy, we need to introduce new tools, technologies, products, and production models through education. In order to transition to a green economy, we can introduce these new items into the field of vocational literacy, including engineering abilities and scientific literacy, which can help students to better understand and solve real-world problems. Scientific literacy can help humanity to better innovate knowledge systems [51]. While the imparting of knowledge is the main content of formal education, its purpose is also to realize the enhancement of students' abilities. Therefore, an important issue that cannot be ignored in formal education is to accurately identify the support relationship between knowledge sets and ability enhancement, that is, the relationship between knowledge and ability. It is the basis for the design of student training scheme and the formulation of syllabus, and is an important basis for the evaluation of student value added. The main means of determining the relationship between knowledge and ability in the past has been based on the experience of teachers, which is the most effective and currently irreplaceable way. The knowledge and ability relationship recognition framework proposed in this paper is a supplement to the traditional experience method, with the aim of optimizing the recognition results of the traditional method. The framework is based on the modular characteristics of complex networks, and the nodes in the module have the characteristics of more similar attributes [52], which is suitable for identifying more related knowledge nodes.

This framework is based on the KCIN, and identifies key knowledge nodes according to the cognitive convergence flow of knowledge nodes. With the key knowledge nodes as the core, the knowledge network modules are identified and the nodes in the modules are taken as the supporting knowledge for capabilities. We applied this method to our Data Structure course and identified the relationship between 42 knowledge points and five capability objectives. To verify the accuracy of the recognition results, we calculated the five capability increments for each of the 114 students enrolled in the course based on their knowledge point scores. First, the results were compared with the capability values derived from the knowledge and capability relationships in the syllabus to measure the difference between the two approaches. Second, the capability increments of the 91 students enrolled in the course were used as the standard to assess the accuracy of the framework. The results show that the knowledge and capability recognition framework based on complex network modularity proposed in this paper can effectively optimize and supplement the traditional recognition methods based on experience.

The influence of the method used to build the KCIN on the relationship recognition result of the framework is considerable, and different KCINs may lead to different recognition results. Moreover, the extraction of knowledge points and abilities mainly relies on the teachers' experience. In terms of ability evaluation, the calculation of ability values is greatly influenced by the α parameter, and the determination of α depends in turn on the teachers' experience. This experience is mainly drawn from three aspects: first, the feedback from teachers on their own capabilities when completing engineering practice tasks with the knowledge contained in the course; second, surveys by graduates about the course, for which the α-value of each capability can be obtained directly from the graduates; and Third, surveys by enterprise engineers, in which the settings for the capabilities and related parameters are generally reflected by the questions on the survey questionnaire. Nevertheless, this framework is advantageous for recognizing the relationship between knowledge and abilities when there are a large number of knowledge points and a wide distribution of content. This is beneficial for breaking the course boundaries and more accurately evaluating the achievement of students' abilities when it comes to student ability assessment, thereby contributing to sustainable development in education.

Author Contributions: Q.Z. contributed to the conceptualization of this study; Q.Z. designed the method of identifying supporting relationships between knowledge and ability; X.S. completed the investigation of student self-evaluation; Q.Z. and X.S. analyzed the data; Q.Z. completed all the visualizations for the paper; Q.Z. and X.S. contributed to the original draft preparation and to the review and editing of the original and revised manuscripts; Z.Z. contributed to the revised manuscripts; Q.Z. and Z.Z. acquired funding that allowed the completion of the study. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: Ethical review and approval were waived for this study due to our study involves a self-evaluation survey of only students administered via an online anonymous survey. Participation was voluntary and the survey was consistent with course objectives without ethical implications.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data used for this study are available upon request to the first author (Q.Z.) or author X.S.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

UAKN	Understanding and application knowledge network
AEKN	Analysis and evaluation knowledge network
KCIN	Knowledge cognitive-interdependent network model
APLA	Advanced programming language application ability
EPEA	Engineering problem expression ability
CSMA	Complex system mathematical model building ability
EPSA	Engineering problem solution design ability
DAPA	Data analysis and processing ability
R&D	Research and Development

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education sciences

Article

Requirements of Modern Russian Agricultural Production for Digital Competencies of an Agricultural Specialist

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Abstract: The purpose of the study is to determine the needs of modern Russian agriculture for specialists with certain, most-in-demand, digital competencies. The research methodology is based on the application of the expert assessments method, the method of random statistical selection of experts, and the scientific generalization method. The field of the research is modern digital technologies in agriculture, as well as the corresponding competencies of Russian agricultural university graduates. The study period is 2021–2022. Having acquired competencies of a modern agricultural specialist at the university should help graduates to integrate into the production process as quickly as possible, the latter undergoing qualitative changes due to the transition to a new technological order based on the use of digital technologies. The study of the current curricula of Russian agricultural universities has shown their lack of adequacy regarding the modern requirements of agricultural production. It indicates the need to examine the curricula. Taking into account the fact that digital technologies are rapidly improving and being introduced into agricultural production, further research in this area should be conducted annually in order to increase the compliance of training at universities according to modern requirements of agricultural production.

Keywords: digital technologies in Russian agriculture; educational programs of Russian universities; competencies of agricultural specialists

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1. Introduction

Digitalization is one of the strategic directions for the development of the modern Russian economy in general and in agriculture in particular. It is to ensure economic growth in the industry, and promote sustainable development of agriculture. In accordance with the national program "Digital Economy of the Russian Federation" [1] and the departmental project "Digital Agriculture" [2], one of the key factors in the implementation of the agro-industrial complex digitalization programs, along with such blocks as digital technologies, regulatory regulation, digital infrastructure, and information security, is appropriate staffing. According to the national program "Digital Economy of the Russian Federation", its implementation requires about 120 thousand university graduates skilled in information and telecommunication technologies, and the share of the population with digital skills should be about 40% (they should be able to work with information obtained from the internet, have skills in working in the internet system, use various internet services, work with application software products and others).

In recent decade, Russian agriculture has been demonstrating a steady growth in the production of its main products, according to Spearman's test. This is largely due to the growth in labor productivity and the use of precision farming technologies that reduce unit production costs and increase crop yields. For this reason, the educational programs of universities, in particular in agronomy, should be updated with reference to new digital technologies at a minimum of once a year. A survey of employees working for leading digital agricultural companies and top managers of the main Russian agricultural holdings have shown that educational programs must be advanced towards the development of the following competencies, according to which graduates of agricultural universities should:

- Know the main trends in the development of modern digital technologies in crop production;
- Use information systems to improve production plans, control operation processes, as well as to prepare reports;
- Know the best practices in the application of both national and international digital technologies in agronomy;
- Possess skills in working with information systems for managing agricultural production (ERP-systems);
- Use mobile applications for visual crop control;
- Analyze weather forecast data from detectors, sensors and other smart devices, etc.

The recent trend in the development of Russian agriculture can be characterized as a steady growth.

A comparison of the development stability of agriculture in the Russian Federation in 2021 with 2010's indicators using Spearman's test (ρ) shows a steady growth in the main products in agricultural organizations (except for grain) (Table 1).

Table 1. Sustainability of production of the main types of agricultural products in the Russian Federation (2010–2021).

Food *	Spearman's Test [1]	Growth Sustainability
Grain	−0.74	unsteady decline
Sugar beet	0.94	steady growth
Eggs	1.0	steady growth
Meat and poultry	1.0	steady growth
Milk	1.0	steady growth

[1] critical test value—0.85. *—These products have been chosen because they are not the main ones in the human diet [3].

However, in relation to the levels of 1990, most types of products have shown a steady decline in production.

Digital technologies are designed to increase the sustainability of agricultural production. The implementation of digital technologies is characterized by the following effects (Table 2).

Table 2. Effects of digital technologies on agricultural production [4].

Direct Effect	Indirect Effect
- Cost savings due to the replacement of manual labor and accounting for consumed raw materials; - Increase in volumes, faster processing of information and acceptance of administrative decisions; - Saving of labor hours, etc.	- Improvement of enterprise performance indicators; - Increase in the number of clients (contractors); - Gain in sales or market segment; - Faster paperwork and provision of services, etc.

The scientific literature widely discusses methodological, economic, technical and philosophical issues of the global economy digitalization [5–9].

However, the lack of a sufficient number of specialists with digital competencies is one of the critical obstacles to the introduction of digital technologies. Each field of activity in a certain period of productive forces development, in particular, digital technologies, needs certain kinds of competencies (in this case, digital ones). The objective of the research was to study the structure of the forecasted need for agronomic specialists with professional competencies in the application of digital technologies in agronomy.

In particular, there is a shortage of qualified agronomic personnel in the country. There was an objective need to introduce new specialties into the high school educational process, providing training for specialists in the implementation of agricultural production and the use of end-to-end digital technologies (big data, neuro-technologies, augmented reality technologies, etc.) The current realities of the global and Russian agricultural sector pose one of the key tasks for universities—the need to develop and update existing educational programs using new indicators for achieving digital competencies. The issue of directions and methods for the formation of digital competencies among university graduates in connection with the digital transformation of the economies of most countries of the world is relevant and widely discussed in various scientific publications [10–13].

At present, it is very important to organize cooperation between universities and organizations that develop digital technologies so that university graduates will be able to work under new conditions [14,15].

Therefore, it is essential to propose new forms of network interaction between universities and enterprises of the real sector of the economy [16,17].

Current curricula for agronomist training are based on professional standards that include digital competencies, but to a small extent. For example, in the professional standards of "agronomist", only a generalized formulation of digital technological abilities in agriculture can be found. It says that an agronomist should be able to "use specialized electronic information resources while collecting the data necessary for operational planning of work in crop production" and "apply geoinformation systems for operational planning of work in crop production." According to the competence "organization of the work of plant-growing teams in accordance with the technological maps of agricultural crops cultivation" in terms of knowledge, they should know "the composition, functions and possibilities of using information and telecommunication technologies in professional activities when organizing the work of plant-growing teams". According to the competency "control of the process of plant development during the growing season", graduates should be able to "use specialized electronic information resources and geoinformation systems when planning and monitoring plant development" [18]. However, this is not enough to be included in the training curricula of agronomists. Particular skills specification is needed and skills of using digital technologies that are in high demand today in Russian agriculture are to be highlighted. The transformation of the educational process in agricultural universities in accordance with the modern realities of agricultural production requires identification and classification of these new requirements based on a scientific approach, substantiating the graduate's competency model.

2. Materials and Methods

The following research methods were applied to achieve the goal—identification of the need for agronomists with professional competencies in the application of digital technologies in agronomy. The sustainability of the development of the production of basic food products was determined by the Spearman test, which was calculated by the formula:

$$\rho = 1 - \frac{5\sum_{\tau=1}^{n}(R_i - S_i)^2}{n(n-1)(n+1)}, \quad (1)$$

where R_i is the rank of the observation x_i in the x series; S_i is the rank of observation y_i in the y series.

The relationship and correspondence between the educational programs of "agronomy" at national agricultural universities and the real need of the market and employers' requirements was analyzed by a scientific comparison method. (Comparison is a scientific method of cognition, in the process of its unknown (studied) phenomenon, objects are compared with already known, previously studied, in order to determine common features or differences between them).

The list of potential employers, including legal entities and/or individual entrepreneurs registered and operating in the Russian Federation for at least 5 years and having at least 100 full-time employees (since digital technologies are introduced mainly by large enterprises), was determined on the basis of random non-repetitive selection with a preliminary selection of homogeneous groups. The list of potential employers included companies: LLC "PhosAgro", agroholding "Dolgov Group", agro-industrial holding "MIRATORG", and LLC "KVS RUS".

To substantiate the conclusions, the results of an individual selective survey with pre-designed questions were used, the logic of which was consistent with the goal: "to analyze the needs of potential employers for specialists with professional competencies in digital crop production technologies." It was considered as a basis for building the competence model of the graduate.

The used methods of expert assessments and forecasting made it possible to predict the need for digital competencies in agricultural specialists for the next 5 years.

3. Results

The surveyed sample included 252 employees from 16 companies and enterprises of various organizational and legal forms, medium and large in size, with more than 100 employees. To determine the competitiveness of a graduate, the respondents were asked to evaluate the significance of some indicators from universities that train agronomists (Table 3).

Table 3. Competitiveness of graduates in agronomy (Bachelor's degree).

No.	Indicators	Test Significance		
		Highly Significant	Significant	Insignificant
1	The quality of training in agronomy	84	16	-
2	Share of employed graduates	64	32	4
3	Qualification of the teaching staff	72	28	-
4	Interaction with agricultural enterprises	78	11	11
5	Availability of modern facilities and resources	62	38	-
6	Use of digital technologies in education	94	6	-

Representatives of the real sector of the economy consider such indicators as the use of digital technologies in education (94%) and the quality of student training (84%) as the most significant for the competitiveness of graduates.

On the other hand, employers think that interaction with agricultural enterprises (78%) and the qualification of teaching staff (72%) are noteworthy for competitiveness.

To analyze the needs of potential employers for professional competencies in the application of digital technologies in agronomy to update the bachelor's program in "agronomy", and "agribusiness", the authors compiled a list of potential employers (which may include legal entities and/or individual entrepreneurs registered and operating in the Russian Federation for at least 5 years and having at least 100 full-time employees) including the representativeness of the sample. The sample included the following companies: PhosAgro LLC, DolgovGroup Agricultural Holding, MIRATORG Agro-Industrial Holding, and KVS RUS LLC.

It was proposed to assess the degree of significance of a particular competence on a scale from 1 to 10, where 10 is the maximum demand for this competence, and 1 is the lowest demand for competence. The questions were open-ended—the specialists of the enterprises could indicate the competencies not included in the list proposed by them.

Further, potential employers were asked to evaluate the importance of several core digital competencies. Table 4 shows the findings of the survey.

Table 4. Significance of the digital competencies of an agronomist, according to the respondents.

Competency	Mean Score (1 to 10)
Know the main trends in the development of modern digital technologies in crop production.	8.93
Use information systems to develop production plans, control work, and prepare reports.	8.93
Know the best practices of applying digital technologies in agronomy (in Russia and abroad).	8.87
Be skilled in information management systems for agricultural production (ERP-systems).	8.73
Use mobile applications for visual crop control.	8.73
Analyze weather forecast from sensors and other smart devices, as well as open access data to develop techniques to reduce the effect of limiting factors in the field crop productivity.	8.53
Know how to evaluate the effectiveness of the digital transformation of crop production.	8.47
Be skilled in compiling and analyzing electronic maps of differentiated application of fertilizers and plant protection products.	8.40
Develop methods for assessing and planning crop yields based on multivariate analysis.	8.40
Know the main features of end-to-end digital technologies and the possibilities of their application in crop production to develop a precision farming system.	8.27
Use information systems with the results of satellite imagery (or UAV) to create electronic maps of actual field contours.	8.27
Know the classification and main characteristics of vegetation indices (NDVI, SAVI, ARVI, EVI, LAI, NDWI, GNDVI, etc.); be able to use their data to develop elements of field crop cultivation technology and plant vegetation management.	8.27
Know characteristics and functionality of the main digital services, including geoinformation, to justify management decisions in crop production.	8.20
Be skilled in compiling and using electronic yield maps.	8.20
Know how to work with portable devices (N-Tester, Green Seeker, SPAD Chlorophyll Meter, and others) to make operational management decisions in crop production.	8.07

A survey of potential employers identified the most sought-after competencies of graduates. The most significant competencies, according to employers (score from 8.5 to 8.93), were as follows:

- To know the main trends in the development of modern digital technologies in crop production;
- To use information systems to develop production plans, control work, and prepare reports;
- To recognize the best practices of applying digital technologies in agronomy (in Russia and abroad);
- To be skilled in information management systems for agricultural production (ERP-systems);
- To utilize mobile applications for visual crop control;
- To analyze weather forecast from sensors and other smart devices, as well as open access data to develop techniques to reduce the effect of limiting factors in the productivity of field crops;

- To be acquainted with effectiveness evaluation of the digital crop production transformation.

The competencies in Table 2 characterize digital hard skills and main digital professional skills of an agronomist. During the survey, respondents were also asked to evaluate what soft skills, transprofessional skills, are most in demand in the context of the digital transformation of the industry. The survey results are shown in Figure 1.

Figure 1. Scoring of digital competencies of a modern agricultural specialist (the assigned score is located along the abscissa axis).

This section may be divided by subheadings. It provides a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that may be drawn.

Employers mostly look for such skills as time management, decision making, responsibility, team building, and conflict resolution.

The development of the competency model of the graduate also considered the recommendations of the industrial working group "Digital Technologies in Agriculture" of the Innopolis reference educational center, namely the basis for training a new generation of graduates in agronomy is the formation of learning outcomes in: analysis of information and process approach in agriculture; use of specialized information services for planning business processes; digital weather forecast stations and use of agrometeorological information in planning and predicting agronomic processes; geoinformation technologies for farming, observing crop rotations, and monitoring crops development; main types and varieties of soils using earth remote sensing (ERS) technologies; use of agricultural machines with modern digital navigation equipment for technological operations; dosing of agrochemicals based on remote sensing data; diagnostics, detection, and prediction of diseases and lack of nutrients for agricultural plants, and the identification of weeds and pests by using a database; landscape crop placement based on GIS technologies; field work reports based on special software and mobile applications; yield mapping systems; monitoring and accumulation of crop development data (field sensors, drone, webcam, navigator, smart weather station, etc.) using internet of things technologies. All these skills are of approximately equal importance for the quality of training of an agronomist with digital competencies.

The pilot project of the Ministry of Agriculture of the Russian Federation to train highly skilled agronomists of the new generation will be the implementation of an educational program based on the end-to-end agro-industrial digital technologies at the Russian State Agrarian University—Moscow Timiryazev Agricultural Academy, that will link all the educational courses of the curriculum and train bachelors and masters to solve the tasks set above (the formation of these digital competencies). That is:

- Research activities: collection and analysis of information using UAVs, artificial intelligence technologies in genetics, breeding, seed production and biotechnology of crops

in order to create highly productive varieties and hybrids; experiments using digital twins of biological systems; generalization and analysis of the results of scientific experiments using packages of applied analytical programs; mathematical modeling of processes based on standard software packages; preparation of data for reporting, reviews and scientific publications based on the use of modern text editors;
- Organization and management: making managerial decisions on the implementation of technologies for the cultivation of new varieties or hybrids of agricultural crops in various economic and weather conditions based on the use of decision support system (DSS); marketing research in agricultural markets using information technology; control over compliance with technological and labor discipline, including with the use of MES- and geo-information systems;
- Production and technological activities: substantiation of the choice of crop varieties for the specific conditions of the region and the level of intensification of agriculture, and the preparation of seeds for sowing using computer databases; compiling soil-cultivating, sowing and harvesting units and monitoring the patterns of their movement through the fields with GPS navigation techniques; organization of a crop rotation system, its positioning on the territory of land use of an agricultural company and the MES-based cutting of fields.

4. Discussion

Nowadays, agricultural companies in most countries have been choosing "industry 4.0" ("agriculture 4.0"). Industry 4.0 is an industrial revolution that involves a new approach to production based on the mass introduction of information technologies into the economy, large-scale automation of business processes, and the spread of artificial intelligence. Agricultural companies are adopting industry 5.0. This is a cyber-social system that allows combining human and machine intelligence to create a collective super intelligence, being a source of harmonious, technological development of human civilization [19].

Numerous research papers note various aspects of the latest digital technologies used today in agriculture and the need to restructure the training of bachelors and masters in order to meet new realities of modern production.

We have previously reviewed up-to-date digital technologies in crop production [20]. Currently, the main trend in the development of agriculture is the use of precision farming technologies based on digital equipment and technology [21].

Today, technologies such as satellite navigation, unmanned and aerial vehicles (UAVs) equipped with various sensors, IoT platforms and big data, and others have already become ingrained in routine agricultural production. Precision farming technologies are widely used in agriculture in all regions of the Russian Federation. This is facilitated, in particular, by the development of unmanned aircraft [22–25]. Machine vision and artificial intelligence technologies [26–30], big data and machine vision are used to predict crop yields [31–34]. The management of agricultural production is developing along with cyber-physical systems using all kinds of sensors [35,36]. This necessitates the restructuring of business processes in the industry and, accordingly, production management, which, in turn, puts forward new requirements for the qualifications of specialists and for the training of graduates of agricultural universities.

The authors of [37] speak about the need to organize a modular approach to the formation of bachelors' competencies and determine the level of formation of each of them, highlighting advanced, basic and threshold indicators at the levels of "knowledge-ability-skills-action", which will improve the effectiveness of the educational process.

The authors of [38] rightly note that universities should constantly be in search of new market needs for the digital competencies of specialists. In our opinion, this should be carried out about once every six months. It is this period that is relevant today for the emergence and promotion of new digital technologies in agricultural production.

The authors write that change in the technological order, and the transition of agriculture to a digital economy, today require universities to take adequate action, to form competencies that have only recently been included in federal educational standards, which today requires a radical reworking of the main educational programs for in-depth study of digital technologies.

The authors have mentioned above, that as the volumes of information have increased, the ability to find the main points in a large amount of information should be added to the new students' competencies. However, in our opinion, today it can be re-placed by the competency of students using various computer services based on big data processing, involving processing of information (including verbal plans) based on mathematical algorithms in order to find the main trends, patterns, etc. From our point of view, in order to bring students' competencies as close as possible to the current market requirements, training should apply a practice-oriented approach, which involves the implementation of such steps as: opening basic departments (on the basis of leading agricultural IT companies), and including representatives of the IT business in the boards of directors of university trustees. The following measures should be used, such as the involvement of employers' representatives in the IT sector in teaching subjects of the professional block, as well as the more active use of such forms of practical training with students as on-site classes.

This, in turn, necessitates the appropriate advanced training of teachers, which, in our opinion, should upgrade the existing qualification of an advanced user.

The conducted research is consistent with the results of individual scientists [39–41].

5. Conclusions

Thus, one of the obstacles to the introduction of digital technologies in agricultural production is the lack of specialists with digital competencies. The transformation of the educational process in agricultural universities in accordance with the modern realities of agricultural production requires identification and classification of these production requirements based on a scientific approach, substantiating the competency model of the graduate [42]. According to the research, representatives of the real sector of the economy consider such indicators as the use of digital technologies in education (94%) and the quality of student training (84%) as most important for graduates. A survey of potential employers of leading agricultural companies showed the most sought-after competencies of graduates (most-to-less important): know the main trends in the development of modern digital technologies in crop production; use information systems to develop production plans and control the execution of work, as well as to prepare reports; know the best practices in the use of digital technologies in agronomy (in Russia and abroad); possess skills in working with information systems for managing agricultural production (ERP-systems); and, use mobile applications for visual control of the state of crops.

In our opinion, in order to bring the competencies of students as close as possible to the current market requirements, training should apply a practice-oriented approach, which involves the implementation of such steps as: opening basic departments (on the basis of leading agricultural IT companies), and including representatives of the IT business in the boards of directors of university trustees. In our opinion, measures should be used such as the involvement of representatives of employers in the IT sector in teaching the disciplines of the professional block, as well as more active use of such forms of practical training with students as on-site classes.

At the same time, universities have certain problems with the implementation of this task, related to the need to improve the digital skills of teachers and fill the materials and resources of agricultural universities with new digital technology.

Since more and more new technologies are being introduced into agricultural production, new competencies of agricultural specialists are vital. Therefore, further scientific research should be carried out every year in order to identify the current requirements of production and the corresponding improvement of the curricula for the training of students in agricultural universities.

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Research on the Teaching Reform of Inorganic Chemistry Based on SPOC and FCM during COVID-19

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Abstract: The COVID-19 pandemic has created a fundamental shift in the Chinese education system, which has compelled teachers and students to accommodate the process of online learning in a short period of time. Accompanied by the advancement of information technology and the emergence of small private online courses (SPOCs), a variety of online programs containing a wealth of new materials and novel pedagogical approaches have emerged. However, there is a lack of awareness among researchers about the efficacy of utilizing shared SPOCs in teaching at conventional universities. Flipped classroom model (FCM) can make up for this defect. This study aims to investigate the effectiveness of flipped learning on the basis of SPOC and to suggest explicit criteria for its reuse in conventional college education. We carried out a quasi-experiment in a course on inorganic chemistry and examined findings with regard to the engagement and performance of the learners. We also conducted a post-task questionnaire and interviews to examine the experiences of the students so that those experiences could be incorporated into the design and study plan for flipped learning based on SPOCs. It was shown that the average performance of students in the flipped SPOC-based classroom was superior to that of students in the traditional classroom. Furthermore, the combination of quantitative and qualitative data showed that the majority of students experienced the flipped classroom favorably regarding student interaction, accessible learning resources, and proactive academic outcomes.

Keywords: SPOC; FCM; COVID-19; teaching reform; inorganic chemistry

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1. Introduction

COVID-19 is spreading swiftly around the world and poses a huge threat to security, public health, education, economy, and employment stabilization. Based on the statistics of UNESCO, there are 1.21 billion students who will not be able to go back to school and university in May 2020, accounting for 69.3% of the total number of students [1].

With the current COVID-19 epidemic also influencing China, the application of online education is suggested to sustain educational events in schools at a national level. To further promote undergraduate teaching during the epidemic prevention and control period, according to the relevant requirements of the competent department of education, the school, and the basic medical college plan in advance, it is necessary to carefully deploy, closely promote, and take multiple measures to carry out online teaching. To guarantee the smooth, orderly, and effective running of undergraduate teaching during the epidemic prevention and control period, the exploration and experimentation of new online teaching are essential. With the development of Massive Open Online Courses (MOOC), the University of California, Berkeley Professor Armando Fox took the lead in proposing a small-scale private online course (SPOC), which mainly focuses on students [2]. Professor Fox believes that the adoption of the teaching paradigm of SPOC in the classroom is not only conducive to strengthening teachers' guidance to students but also promotes students' participation through learning platforms and corresponding curriculum resources [3,4].

The Flipped Classroom Model (FCM) is a blended learning model that aims to facilitate teachers to make better use of the face-to-face sessions by minimizing teacher lectures and increasing students' active learning, collaboration, and scaffolding. In recent years, the flipped classroom model (FCM) has constantly shocked, thrilled, and inspired faculty via the incorporation of PowerPoint-based presentations into conventional classroom instruction. Moreover, FCM supposes a general designer for online and face-to-face learning, that is, the in-school tutor.

SPOCs provide an alternative to the design of flipped learning, where instructors are able to flip their classes with available SPOCs. With this method, in-school course students are required to attend SPOCs that are designed and deployed by other organizations. SPOCs are a fairly novice technology that has not yet been "normalized" for daily practical purposes [5]. A growing body of SPOC studies centers on the integration of SPOCs as part of a more general pedagogy. The SPOC-based flipped classroom is an effective and sustainable teaching model to promote teaching. Nevertheless, SPOC-based flipped classroom remains in an early phase. While research on the perceptions and behaviors of students is scarce and no comparative analysis of SPOC-based flipped classroom and traditional learning has been conducted, studies on its practicality and strengths from a teaching and mental science viewpoint have been deficient. As a quasi-experimental study, the purpose of this research is to incorporate shared SPOCs into typical classroom practices in bachelor's courses. In particular, it examines the experiences and academic performance of students under this burgeoning learning paradigm. Before presenting the research methodology, a summary of related literature on the practice of SPOCs and flipped classrooms will be provided.

2. Literature Review

2.1. SPOCs

SPOC is an acronym that refers to a small-scale, limited online course. Small is changed to massive in MOOC, which refers to the implementation of the flipped classroom. The number of objects is the number of school students, and the number is small; private is changed to open in MOOC, which means that only recognized learners on campus have access to these resources. "Minority" means that the number of students is generally in the dozens. Therefore, it has also become a "private broadcasting class" [6]. The advantage of SPOC lies in its customization and privacy. SPOC can fully customize a series of teaching links from time and space to learning objects and teaching contents. At the same time, SPOC teachers can choose whether the customized teaching contents are public, which not only ensures the teaching quality of SPOC but also protects the personal privacy of SPOC learners. SPOC provides more detailed and accurate personal data analysis services, which effectively monitor learners' learning behavior and the learning effect in each specific time period. In the online learning stage, SPOC teachers make some important teaching arrangements (such as homework, experiment, examination, etc.) and adopt the mixed teaching mode most prevalent in flipped offline classrooms to enhance the teaching quality in traditional classrooms. This new model not only incorporates the unique strengths of MOOC and SPOC but also makes up for the quality crisis caused by MOOC large-scale learning [7]. In MOOC, the content and style of teaching, educational philosophy, and technological platforms are enhanced [8,9]. SPOC classroom activities adopt a variety of learning methods, such as team learning, collaborative training, and inquiry learning [10], which realizes the comprehensive and in-depth integration of online learning and traditional classroom teaching to a certain extent.

2.2. SPOCs-FCM

The research on the flipped classroom model (FCM) based on SPOC originated from Harvard University. Researchers carefully created small-scale and restrictive online courses for teaching students. In addition, the FCM also creatively teaches by combining SPOC and flipped classrooms so as to promote an efficient connection between MOOC high-quality resources and the online evaluation system, and thus ensure high-quality teaching in the offline physical classroom.

In 2013, the first SPOC platform in China created by Tsinghua University—"zhixue-yuan"—was officially launched, and teaching practice based on flipped classrooms was carried out successively. So far, China has begun to focus on the integration of SPOC and flipped classrooms. On the basis of the background of the post-"MOOC" era, Li et al. [11], based on the background of the post-"MOOC" era, deeply analyzed the connotation of SPOC, advocated taking "experience and personalization" as the internal source of power of learning, and created an SPOC experiential learning model based on distribution reversal. Xue et al. [6] first analyzed the essence and advantages of the teaching model of the SPOC flipped classroom and then designed the teaching model of a flipped classroom of SPOC with the typical characteristics of "four threes" in computer foundation courses.

Lin et al. [12] looked at the dilemma in that students' innovation abilities could not be sufficiently supported under the conventional teaching model and constructed a teaching model integrating "online and offline" SPOC and a flipped classroom. Based on the learning characteristics and practical needs of college students, Zhu [13] strived to study the localization of SPOC and flipped classrooms and designed a flipped classroom teaching model for higher education institutions on the basis of SPOC. Ding et al. [14] improved and sublimated the flipped classroom. While emphasizing the importance of knowledge and skills, they advocated paying attention to students' personalization and comprehensive ability training and carefully constructed a "flipped classroom 2.0 teaching mode based on SPOC". Chen et al. [15] put forward the mixed teaching mode of analytical chemistry course based on SPOC and expounded the principles and ideas of course analysis, overall design, resource development, teaching process, and evaluation design. The mixed teaching environment and the implementation of analytical chemistry based on flipped classrooms were discussed.

2.2.1. Students' Participation

As a teaching model with stronger teacher–student interaction, the flipped classroom helps to improve the engagement of students. The class time can be occupied by student-centered learning activities, such as exploring and problem-solving, through face-to-face instruction by the teachers. As a result, the class time becomes more interactive [16]. The typical practice of flipping the classroom combines microlectures with practices based on the theory of humanistic learning, which achieves "re-education with video". One study compared student performance in flipped-learning and traditional classes. Student performance was enhanced when using the flipped-classroom methodology, with 83% of the students gaining a C grade or better, compared to 56% when using a traditional course methodology [17]. Currently, only a few studies have compared student grades of students in a traditional classroom with those in a flipped classroom using SPOC technology.

Wang et al. [18] introduced the novel concept of "MOOC + SPOC + flipped classroom" hybrid teaching and proposed that local universities should "make good use of MOOC", building "SPOC" and grasping "flipped classroom" as the foundation, and build a new mixed teaching model in line with the reality of local universities to achieve the expected results. Based on Flanders' interactive analysis system theory [19], three experiments were carried out in three classes of the same major, using the same heterogeneous class model, and classroom records were used to evaluate and make comparisons between the interactions in the traditional and flipped classroom. The results showed that the proportion of students' effective discussion, communication, and speech in class increased greatly; the students actively participated in learning; and student-centered teaching gradually took shape.

Zheng et al. [20] combined SPOC online learning activities with the process design of the flipped classroom and built the structural framework of a teaching model from four parts: curriculum objective and content design, teaching strategy design, learning activity design, and teaching evaluation design. According to the findings, the application of SPOC flipped-classroom teaching was conducive to stimulating students' enthusiasm for participation and promoting the development of students' thinking skills and hands-on operation abilities, thus contributing remarkably to the improvement of the teaching effect.

2.2.2. Experience and Academic Performance of Students

Concerning student experiences, there are a variety of studies indicating that students share favorable perspectives regarding the flipped-classroom approach. For instance, a report used SPSS to conduct an independent sample t-test on the midterm exam scores and compared experimental and control classes. The results showed that the scores of the experimental and control classes were dramatically different at the level of $p = 0.05$ (F = 3.282, SIG = 0.041), and the experimental class had higher test scores than the control class obviously (M experimental class = 89.000, m control class = 81.406) [21]. A questionnaire was designed using Likert's five-point scale, which was scored from negative to positive according to 1–5 points, including 3 dimensions: basic situation, teaching form, and teaching effect. After the initial test, the questionnaire yielded a Cronbach's alpha coefficient of 0.964, so the reliability of the questionnaire was good [22].

A study involving 752 undergraduates showed that they preferred SPOC rather than traditional pedagogical methodologies [23]. Lu Hua reported that in linguistics courses, the students preferred SPOC over MOOC, and a SPOC-based learning model had its advantages and was shown to be effective in a demonstration of its application [24].

Research on flipped learning has been increasing dramatically in recent years as its utilization in educators' practices has increased [25,26]. Flipped classrooms can generate higher final exam scores compared to online and traditional studying. Egbert, Herman, and Lee [27] and Leis, Cooke, and Tohei [28] affirm that flipped learning can be of great help to students' language learning. Strayer [29] states that flipped classrooms facilitate students to be more open to cooperative study in courses on statistics. An increasing number of studies have centered on flipped-classroom design, with an emphasis on the ways in which flipped classrooms can facilitate student engagement and achieve better academic performance [30,31].

2.2.3. The Role of Student Variables

This study concentrates on the impacts of flipped learning based on SPOC on two student-centered variables, SN (subjective norms) and SE (self-efficacy). SN reflects an individual's perception of the importance of using SPOC cloud class. Teo et al. found that the higher the subjective norms of students, the stronger the learning intention [32]. Zhao et al., through an empirical study, claimed that subjective norms positively influence students' continuous learning in online open courses in a significant way [33]. Yuan et al. used a structural equation model to explore the pronounced positive effect of subjective norms on students' mathematics learning behavior [34]. SE is described as a person's faith in his or her capacity to accomplish the actions required to generate a specific achievement of performance [35]. SE indicates confidence regarding one's capacity to manipulate their motives, actions, and social context. Lai and Hwang [36] asserted that the methodology of the flipped classroom has obvious benefits for students' SE. In a study, similar efficacy was also observed, wherein students taught with flipped learning methods were superior in SE to those who learned with conventional teaching [37].

2.2.4. Research Objectives and Research Questions

This study aims to examine how SPOC-based flipped learning (SBFL) influences students' academic performance in inorganic chemistry courses at the undergraduate level. In particular, there are four key research questions in this study: (1) what kind of challenges do students face, and what adaptation strategies do they use to cope with these challenges while studying inorganic chemistry in a flipped classroom? (2) What are their perceived learning outcomes due to participation in SBFL? (3) How do the students think about the learning platform they choose in the flipped classroom? (4) After completing the program, do students have an increased SN and SE in the SBFL environment?

3. Methodology

To examine and compare the validity of flipped learning based on SPOC, this research adopted a quasi-experimental design. Moreover, it combined the collection of both quantitative and qualitative data to enable us to obtain a more holistic knowledge of the experiences and opinions of students in the context of SPOC-based flipped learning. Our data consisted of three categories: firstly, student engagement, that is, viewing of microlessons and taking online tests. Secondly, data were grouped in the experience as well as the pre- and post-test academic performance of the students. Finally, we also included students' interview data from the quasi-experimental group.

3.1. Participants and Setting

This study chose two classes of first-year chemistry majors from Harbin University in 2019, with 34 and 35 students in each class, respectively. Most of the students utilized SPOCs for the first time. SPOC-based flipped learning was applied to a group of 34 students. The control group comprised 35 students, and both groups were given lessons by the same instructor. Inorganic chemistry is a three-credit course that is taught two times per week for 90 min on Mondays and Thursdays in the winter 2019 semester. Courses lasted 18 weeks, and our quasi-experiment ran for 6 weeks, commencing in week 12 and ending at the end of the semester. A number of higher education institutions provide similar courses on the MOOC platform of Chinese universities. Upon discussion with the instructor, we chose to adopt the course on inorganic chemistry produced by Dalian University of Technology, which consists of 11 chapters, each comprising 6 to 8 microlessons, each of which is around 12 min in length.

3.2. Learning Process and Events

Once the quasi-experiment starts, an account on the SPOC platform is required for every student in the flipped classroom to watch the microlessons and complete the online practices. The flipped classroom consisted of two sections: pre-class and classroom events. Students were requested to view two to 3 microlectures on the SPOC platform prior to every class, an example of which is shown in Figure 1. Once the microlectures were viewed, students were asked to finish 10 drills. Because faculty in the prospective experimental class lacked access to see the data of students on the platform, students were required to note their wrong answers to the exercises by hand upon completion of the task, which is shown in Figure 2. In the classroom, students were separated into 7 groups of about 5 students each. For the first 45 min, students attended group discussions, exchanged their ideas, and talked about the reasons for their erroneous answers to the online practice. The instructor provided instruction individually to the students who raised questions throughout the discussion, and the engagement of the students is shown in Figure 3. In the closing of the discussion, students were requested to present issues and themes which they had not fully understood. After that, in the following 45 min, the lecturer highlighted the topics presented by every group. Accordingly, traditional class students received conventional face-to-face teaching for 90 min. In a traditional class, the instructor guided the teaching, lectures, or presentations while students viewed, heard, and made notes.

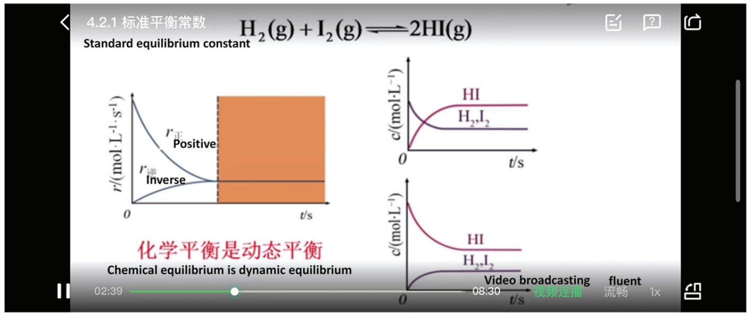

Figure 1. Example of microlecture with slides.

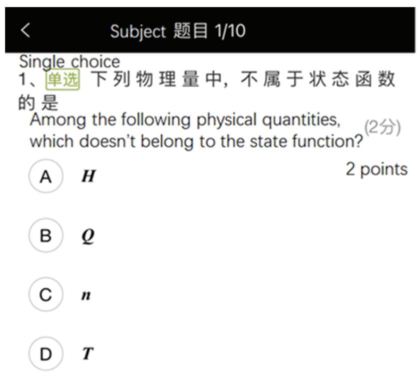

Figure 2. Example of an online practice for a selected course. Each unit of the course platform has a matching exercise test, submission deadline, and corresponding scores. Students can use those online exercises to test the effect of watching the video.

Figure 3. Panel discussion for the face-to-face class. During the first 45 min of the face-to-face class, students in each group talked about the issues they could not understand while watching the video and practicing online before the class. Meanwhile, a leader was assigned to each group who was in charge of the group's self-discipline.

3.3. Tools

Students were given a research instrument that comprised two subscales with an emphasis on SN and SE at the start and end of the study [20,38]. Learner SN was measured by five items, and a sample statement was "SPOC has a significant meaning to me". Learner SE was measured by four items, and a sample statement was "I have the ability to use SPOC to study the materials from both computer and mobile". Detailed questionnaire survey is labeled in Appendix A. The questionnaire was administered on a five-point Likert scale using "strongly disagreed (SD) as 1, "disagreed (D)" as 2, "agreed (A)" as 4, and "strongly agreed (SA)" as 5, whereas "neutral (N)" was 3. To measure students' experience of flipped learning based on the SPOC, we also carried out a post-mission questionnaire, which was adjusted from the Student Perception of Instruction Questionnaire (SPIQ). The questionnaire consisted of 15 closed-ended questions about students' perceptions of the content and instruction of the course, evaluation and assessment, and exchange and study experiences. Students were surveyed by the time they finished the course. Responses to each question were devised with a 5-point Likert scale, which is shown in Table 1.

Table 1. Post-task questionnaire items and results on students' experiences with SPOC-based flipped learning.

No.	Items	SD	D	N	A	SA	Mean
Q1	In the past 6 weeks, I have mastered the basic theory and knowledge	1	4	5	19	5	3.68
Q2	In the past 6 weeks, I am interested in expanding my knowledge.	2	6	4	18	4	3.47
Q3	I can make comprehensive use of what I have learned, such as, for example, to carry out chemical experiments and explain chemical phenomena.	1	3	6	17	7	3.76
Q4	During the last 6 weeks, my learning efficiency has improved.	1	3	8	19	3	3.59
Q5	During the last 6 weeks, my interest in learning has improved.	2	2	4	20	6	3.76
Q6	During the last 6 weeks, my teamwork has improved.	2	4	6	18	4	3.53
Q7	My technical communication ability has improved.	3	5	6	16	4	3.38
Q8	I have an interdisciplinary and professional vision.	1	3	5	18	7	3.59
Q9	Hands on ability has been enhanced.	3	5	5	16	5	3.44
Q10	The ability to innovate has been enhanced.	4	6	4	14	6	3.35
Q11	The autonomous-learning skills has been improved.	1	3	5	19	6	3.76
Q12	I have the ability to find information and collect information.	2	4	5	20	3	3.53
Q13	During the last 6 weeks, I prefer to communicate with teachers.	2	2	6	19	6	3.82
Q14	I have set up a scientific ideal and have the spirit of scientific research and exploration.	1	3	4	20	6	3.79
Q15	The ability to solve problems independently has improved.	2	4	6	17	5	3.71

3.4. Interview

Following the flipped-learning experience, qualitative data were captured through semi-structured face-to-face interviews, which were conducted in accordance with the following ten instructional questions: (1) How did you feel in flipped classroom? Why? (2) What challenges did you face at the beginning? How did you solve them? Where teachers' support sufficient to adjust to flipped classroom learning? (3) Please share how did you study on SPOC cloud class? How did it help your learning? How effective was the platform? (4) How did you feel sharing your views/comments on SPOC cloud discussion forum? What are the benefits of sharing views in your learning? What challenges did you experience? (5) Please give an example of the video materials that you liked most. Why? What skills were developed? How? Please comment on the quality and quantity of the videos/lecture materials? (6) It is seen in most classes you took quiz using mobile phone. What are the benefits of taking quiz using mobile phone. What are the benefits of taking quiz using technology in your learning? How? (7) Please share one classroom activity that helped you in your learning. What parts of the class were most difficult? (8) What study habits have changed as a result of taking this class? How would you describe your relationship with your classmates? Please describe your views on teachers' role? (9) Did you face any challenges in performing in class activities? In which flipped classroom did you learn more? How? (10) Would you recommend this type of learning method to other students? Why?/Why not? Interviews lasted from 30 to 40 min, and all were recorded with audio, annotated, and transcribed to allow later analysis of the data.

3.5. Academic Performance

Academic performance was assessed by the final mark obtained by the end of the semester to investigate the level of change caused by the variables studied in the quasi-experimental conditions, and the final mark was calculated on a scale from 0 to 100.

3.6. Data Analysis

The present study employed SSPS 23.0 to perform an analysis of the data gained from the questionnaire, the pre-test, and post-test. Initially, we investigated the data through descriptive statistics to examine the means, standard deviations, and frequencies. This study then employed independent *t*-tests to identify differences in previous knowledge, SN and SE, and their opinions of the flipped learning context between the two groups. Pairwise *t*-tests were conducted to examine the differences in SN and SE between the experimental groups. We proceeded to employ an analysis of covariance (ANCOVA) to measure differences in the post-test academic performance between the two groups, with prior knowledge being included as a covariate. Lastly, we utilized MAXQDA 12 to conduct an analysis of data obtained from semi-structured interviews regarding students' views on the flipped-learning context.

4. Results

4.1. Students' Engagement in Completing Microlessons and Exercises

Completion of the microlearning showed a higher percentage than 60%, shown in Figure 4, demonstrating that students were inclined to finish the videos as they participated in them. It is estimated that 75% stated that they viewed over half of the videos in their experiment completely. In addition, there was a maximum number of students who watched all of the videos in week 4.

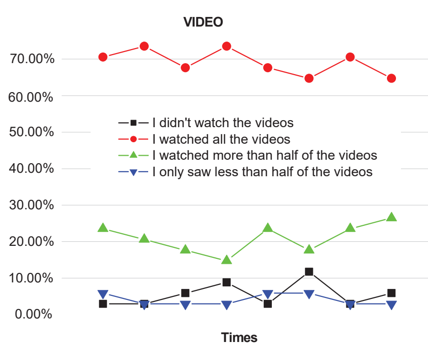

Figure 4. Results of the frequency of viewing microlessons. The horizontal axis represents times students were asked to engage in watching the video, and the vertical axis represents the rate at which students finished watching the video. The number of students who viewed and finished the video every time is far higher than those who did not finish the video in the graph.

Around 50% of the students accomplished an excess of half of the online exercises (as shown in Figure 5), and there were 19 students who finished everything in the second week. Nevertheless, this dropped to approximately 16 every time in the following weeks. From week one to week five, the number of students who failed to perform the practices increased from one to six (17.6%), a number that fluctuated over the next few weeks.

Along with the course, the timing of the microlessons and assignments was distributed differently. Students who engaged in the SPOC were driven and motivated to view the microlessons and perform the drills before the initial two sessions, which enabled students to originally cover a high proportion of the videos. The practices occasionally did not appeal to students because they did not offer explicit interpretations of the right responses.

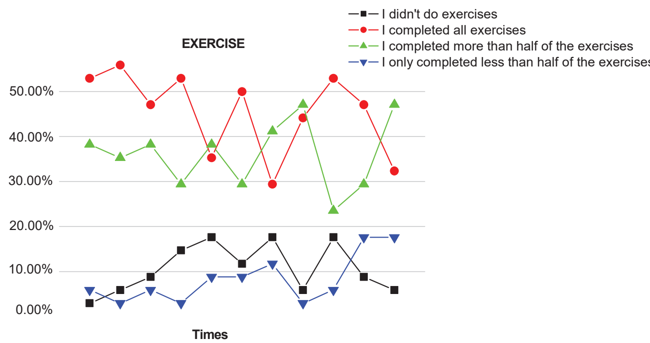

Figure 5. Results of online practices. The horizontal axis represents the number of times required for students to accomplish the online practices, and the vertical axis represents the rate of finishing the online practices. The graph shows that there were far more students who accomplished the online practices every time than those who did not finish them.

4.2. Analysis of Students' SE and SN

To explore if there were major differences between pre-test and post-test SN and SE in a flipped-learning environment, this study conducted a comparison of testing scores by applying a paired-samples *t*-test. According to the results, there was no major discrepancy between the SN and SE scales before and after the test ($t = 0.75$, $p > 0.05$), so there was no obvious difference between the students' SN and SE pre- and post-flipped learning.

4.3. Learning Performance

Pre-tests were carried out in both groups to evaluate students' previous cognition of the curriculum content. The mean score for the control group was 38.20, and the mean score for the experimental group was 40.16. It was revealed by an independent *t*-test that there was no apparent disparity between the pre-test scores of both groups ($t = 0.81$, $p > 0.05$), which indicated that the two groups possessed similar prior knowledge regarding the course curriculum ahead of the experiment. Upon conducting the learning sessions, ANOVA was selected to investigate the relationship among the post-test scores of both groups—with the pre-test marks as the covariate, the post-test marks as the dependent variable, and "different learning environments (two groups)" as the controlled variable. Findings of the ANOVA showed a considerable difference between the post-test scores ($t = 4.82$, $p < 0.001$) of the experimental group (M = 72.92) and the controlled group (M = 64.61) while keeping the pre-test scores under control.

4.4. Student Experience Analysis

Survey results are shown in Table 1, where we merged "strongly disagree" and "disagree" as negative replies, while "agree" and "strongly agree" were merged as affirmative replies. Across the 15 items, 70.6% of students mastered basic theory and knowledge. Students were further questioned about their participation in the content and materials they learned, and the majority of interviewees (64.7%) found it interesting to expand their knowledge of this course in the previous 6 weeks. Most interviewees felt that they made comprehensive use of what they had learned (70.6%). Meanwhile, skills such as learning efficiency (64.7%), learning interest (76.5%), teamwork and cooperation (64.7%), technical communication ability (58.8), interdisciplinary and professional vision (73.5%), practical ability (61.8%), innovation (58.8%), and autonomous-learning skills (73.5%) were highly developed. A total of 73.5% of the interviewees showed positive opinions about teacher–student communication.

Semi-structured interviews were then administered to interpret this finding more fully. A total of 10 of the 34 students interviewed took part in these interviews. Using five instructional interview questions, the researcher managed to code each recording, and the findings are presented in Table 2. 80% of the students replied that it was their first time taking this course. They were only initially intrigued during the study, after which 70% of the students remained in favor of conventional face-to-face instruction for different reasons. Eighty percent of the students gave high marks to the quality of the microlessons, and the majority stated that they enjoyed viewing the microlessons through the platform in order to gain a better insight into a concept or a topic from the textbook. More importantly, a number of students had absolutely no trouble seeing the videos but had trouble figuring them out on their own. Relatively speaking, a mere 30% of students felt that the overall quality of the online practices was found to be at a generally high standard. A total of 80% of students rated student–student communication, and 70% of students rated student–teacher communication favorably, stating that they felt the flipped classroom enabled them to take a significant amount of time in class to discuss their issues with the instructor and classmates. A total of 90% of the students used their time outside of class to see the microlessons, and 80% of the students felt that they were able to become more active in their learning by flipping their studies.

Table 2. Students' experience of flipped learning based on SPOC.

Subject	Topic	Percentage
Overall experience	Reward	8 (80%)
	Shortage	7 (70%)
Learning content	Microlectures	8 (80%)
	Online exercises	3 (30%)
Learning interaction	Student–student communication	8 (80%)
	Teacher–student communication	7 (70%)
Learning motivation	Watching time	9 (90%)
	attitude	8 (80%)
Self-evaluation	Self-efficacy	5 (50%)
	Self-regulated learning	3 (30%)

5. Discussion

With regard to RQ1 (what are the challenges faced by the students and what adaptation strategies do they take to cope with these challenges while studying inorganic chemistry in the flipped classroom?), the research instruments employed in this study consistently gave evidence that students experienced various challenges, namely, a lack of confidence to communicate, forgetfulness, a lack of self-learning skills, and workload, when they entered the flipped classroom. The students faced these challenges because of their long exposure to traditional teacher-centric and textbook-dependent learning practices in their schools. Therefore, to cope with the active learning environment of the flipped classroom, the students took various initiatives, such as motivating themselves to communicate, acquiring autonomous learning skills and self-control, developing cooperative learning, and managing learning through technology. Students took these initiatives on their own because they found the flipped classroom opportunistic and supportive of learning.

Secondly, as for the RQ2 (what are their perceived learning outcomes due to participation in SBFL?), the flipped classroom creates a more engaging learning environment than the usual traditional classroom. Therefore, students' experiences with this more engaging and less-effective learning environment help them to develop confidence, performance, and various lifelong learning skills. As Chinese students tend to be quiet, their engagement in various cooperative activities promotes them to be active and expressive. It was shown that in contrast to students in the controlled group of conventional learning, students who were taught in a flipped learning environment showed superior achievement in academics. This finding is in line with other studies [38,39]. This may be associated with students' proactive participation in watching the microlessons and due to the curriculum design that allowed them to spend additional time beyond class to deal with the information presented in the microlessons. Students were able to avail themselves of the microlectures they viewed in this course, backing up the assertion that microlectures are an effective instrument for reaching the intended academic objectives [40]. In addition, the online practices presented a just-in-time approach to reinforcing learning after viewing the microlectures, by facilitating students' greater command of acquired knowledge. It has been shown that when lessons are individualized and tailored to personal needs, students perform better and gain a deeper appreciation of notions [41]. In line with earlier studies, our findings suggest that flipped learning causes higher levels of student readiness for the classroom [42], as it permits a more efficient use of class time and empowers students to incorporate information and to reflect critically on it [43]. Different from typical classroom settings, the flipped method facilitates student involvement [44] and promotes collaborative problem-solving. Our outcomes are consistent with Richardson, Abraham, and Bond's [45] description of proactive learning, who believe that flipped-teaching methods have a favorable influence on in-class learning by enabling students to assume responsibility and take initiative. This is due to the fact that prompt person-to-person instruction in question-and-answer periods with the instructor aids students in perceiving that their private matters and attention count. Furthermore, following small group presentations, the instructor can readily respond to frequently asked questions before the class.

Thirdly, another very important finding is the reason for students' behavioral intention to use the SPOC cloud class and how much they are satisfied with the platform, which answered RQ3 (how do the students perceive the platform selected for learning in the flipped classroom?). Although previous studies have worked on SPOC cloud classes, almost none of them particularly focused on first-year students majoring in inorganic chemistry. Therefore, this study's findings can be used to appropriately design a flipped classroom equipped with an SPOC cloud class for freshmen. It is evident that Chinese freshmen have positive subjective norms of using the online platform.

Fourthly, regarding RQ4 (will students' SN and SE in the SBFL setting increase after the completion of the course?), one needs not only an insight into the supervisory process but also into its determinants for the facilitation of SN. To what degree students utilize their SN will greatly rely on their motives [46,47], and students could possibly develop their SN through the use of controlled or self-directed motivational procedures [48]. Moreover, Hart and Friesner suggested that Chinese learners may possibly find themselves submissive to their tutors [49]. The results of our interviews reveal that these students entered university just after passing the college entrance exam, so they have become familiar with their instructors' routines for study. Although some students engaged in flipped learning on demand, they displayed almost no indication of SN in terms of watching microlessons, tending to do so only when the teacher declared the deadline in an online group of the class. The findings of our study are in disagreement with prior research findings [50] indicating that the experience of the context of learning leads to alterations in SE levels, for which several interpretations can be proposed. To begin with, a six-week research duration is likely too limited to allow for the detection of variation in SE. Furthermore, variations in student variables are likely to be influenced by students who operate in an unknown learning context.

6. Conclusions and Implications

The efficacy of flipped learning based on SPOC was proven in this study through an applicable quasi-experimental study. It was shown that the flipped learning design based on SPOC could boost students' academic achievement. A further important discovery was that students experienced microlearning and online practices in a positive way. This study holds vital significance that can inform instructors and SPOC developers in the future. Firstly, we identified challenges that students faced while attending SPOC flipped classrooms in inorganic chemistry. The challenges students faced and strategies that students took to cope with the student-centric learning environment were cross-verified. In combining SPOCs with their own teaching approaches, faculty require reflection on ways to make sure that their pedagogical resources and online materials accompany each other to assist students in the comprehension and grasp of challenging issues and knowledge.

Despite the fact that the primary goal of the study was accomplished, it is important to be aware of the limitations of this study. In our quasi-experiment, the first constraint is the possible influence of extrinsic circumstances on the results. Cause–effect extrapolation from the quasi-experiment would be finite because attendees had not been stochastically allocated to a given condition. Due to the syllabus and course setting, students in two college classes frequently could not opt for the experimental or controlled group willingly.

In conclusion, for future studies, experiments in which there is a random allocation of persons to situations under conditions will contribute to the reproduction or examination of our findings. The next constraint is that the limited sample size of the quasi-experiment probably does not allow extrapolation of the outcomes to other examples or other contexts. In addition, the SPOC design of our study is designed to look only at campus students in China; it is possible that future research in other nations with different scholastic cultures, in terms of attitudes, values, and other modes of behavior, may yield diverse findings. Furthermore, the analytical findings and results of this study are subject to interpretation with caution due to time limitations since the curiosity of students to use SPOC may affect the findings of the research over a short period of time. Last but not least, though visibly in the flipped classroom responsibility is shifted from teachers to students, it actually diversifies teachers' roles as an instructor and increases their working hours. The influencing factors of teachers are also worth studying. Accordingly, further studies may investigate matters of interest through bigger sample sizes and lengthier time trials.

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Appendix A

This survey is to understand your overall learning perception of the use of SPOC in the course. There is no right or wrong answer. Please circle the answer which best reflects your overall thoughts about each statement. Your answers are ANONYMOUS and CONFIDENTIAL. Thank you in advance for your time.

Table A1. The survey of Subjective norms and Self-efficacy.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

Subjective norms (SN)						
SN1	SPOC has a significant meaning to me.	1	2	3	4	5
SN2	It is necessary to conduct SPOC to meet the need of society.	1	2	3	4	5
SN3	It is beneficial for me to experience SPOC for my future job.	1	2	3	4	5
SN4	People who are important to me think that I should use SPOC.	1	2	3	4	5
SN5	It is necessary to learn more use of technology in classroom for better future.	1	2	3	4	5

Self-efficacy (SE)						
SE1	I have the ability to use SPOC to study the materials from both computer and mobile.	1	2	3	4	5
SE2	I have the ability to find the learning resources on SPOC.	1	2	3	4	5
SE3	I know how to watch videos and write comments on SPOC.	1	2	3	4	5
SE4	I have the skills required to use to enhance the quality of my learning.	1	2	3	4	5

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sustainability

Article

Structural Model Analysis of Factors Affecting Sustainable Teacher Job Satisfaction in Korea: Evidence from TALIS 2018

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Abstract: This study aims to explore the relationship between the preparedness, self-efficacy, career motivation, and job satisfaction of Korean teachers with the 2018 data of TALIS (Teaching and Learning International Survey). For this purpose, 1266 Korean middle school teachers were selected, and an analysis of mediating effects was executed by utilizing structural equation modeling and phantom variables. The results are as follows: teacher preparedness had a significant and positive effect on teacher self-efficacy and career motivation. However, it failed to show a significant effect on teacher job satisfaction, which was instead significantly and positively affected by teacher self-efficacy and career motivation. In addition, based on the analysis of the estimate of mediating effects, it was discovered that teacher career motivation had a greater positive effect than that teacher self-efficacy on teacher job satisfaction. Taking these results into consideration, this study accordingly makes suggestions concerning the improvement of sustainable teacher job satisfaction, self-efficacy and career motivation inside teacher education courses. Furthermore, this study will propose measures such as further valuing the Teaching Personality and Aptitude Test and strengthening in-depth interviews in student teacher selection, extending teaching experiences through simulated instruction and peer supervision as well as providing well-organized teaching professional counseling opportunities for student teachers.

Keywords: sustainable teacher education; teacher job satisfaction; preparedness; self-efficacy; career motivation; TALIS

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1. Introduction

The renowned educational psychologist Haim Ginnot begins his work (1993) with a depressing conversation on the well-being of teachers [1]. This conversation, under the subhead *The Theme of Despair*, is filled with grumbles about how teaching could be such an unsatisfactory profession. The anecdotes shared therein are powerful indicators of how important teacher job satisfaction has been not only for teacher's well-being but also for educational research as a whole.

The teacher is undoubtedly a crucial part of education; thus, teacher job satisfaction is also a major factor in whether education is successful as well as sustainable or not. The fact that higher teacher job satisfaction leads to better student achievement has already been identified in previous studies [2–4], and that teacher job satisfaction has a positive correlation with the school's climate and culture has been affirmed through previous studies [5–7]. Additionally, many studies have already been conducted on external factors (pay, forms of employment, position, job conditions, etc.) as well as internal factors (sense of accomplishment, responsibility, challenge, the potential for development, etc.) for enhancing teacher job satisfaction [8]. Curiously, these studies share one thing in common—each one concerns the time after starting one's professional teaching career. Thus, one could say that these studies concern the external situations and internal changes felt by incumbent teachers, those already finished with teacher education

However, it is insufficient to define teacher job satisfaction with these external and internal factors. We need also to consider the pre-service motive for pursuing the teaching profession, the process for becoming a teacher, and what psychological preparation went into that process. When the main focus shifts to the enhancement of teacher job satisfaction based on the external and internal factors—respectively the school and the mentality of the teacher—such grumblings fall outside of the field of consideration or are only supplemented with OJT. The reason behind this is that teaching is always in progress, teachers are already thrown into the field, and their teaching career is irreversible.

However, if one were to actively identify the cause for the dissatisfaction with teaching and use that knowledge to enhance the job satisfaction of teachers, the boundaries of our studies be inevitably and sustainably expanded to that of the teacher education course. Teacher preparedness not only affects the efficacy of the teacher from day one but will also hold an undetachable connection with the overall level of satisfaction maintained throughout the whole teaching career. Above all, since the job satisfaction of the teacher is directly connected to the well-being of the teacher as an individual human being—not just as a professional worker—it must be acknowledged as a subject of extensive research.

The stronger the process of training the teacher becomes (in both quantity and quality), the deeper the correlation between the teacher's preparedness, job satisfaction, self-efficacy, and career motivation becomes [9–11]. Thus, when decisions leading to a teaching career are made at younger ages and the more the process becomes unitary or exclusive, the density of teaching preparation will trend upwards. Therefore, the main question is exactly what kind of character and substance of teacher preparedness training is to be pursued in our society. Since, as mentioned before, the preparedness, job satisfaction, self-efficacy, and career motivation of teachers are not simply a matter of the teacher as an individual; they affect the achievement of the students, the sustainability of school organization, and educational culture as a whole.

This study focuses on the case of South Korea in particular. As in the case of Australia which has different ways of teacher education (Bachelor of Education, Bachelor of Science or Bachelor of Arts with Bachelor of Teaching, and Bachelor of Science or Bachelor of Arts) [12], Korea also has maintained a relatively open teacher training system for the past several decades. From the traditional teacher's college to the teacher education courses of non -teacher's colleges to graduate schools of education, the gateway to the society of professional teachers have been open to various groups. While the states and territories are responsible for the registration of teachers, conditions for teacher employment as well as qualification requirements in Australia [13], the Ministry of Education provides the guidelines and standards to universities, colleges, and graduate schools in Korea. Within the boundary of certification standards for teacher education (subjects, credits, practice, etc.) outlined by the Ministry of Education, but with a certain amount of autonomy, flexibility and sustainability, universities have trained the prospective teachers.

Yet, according to the new teacher education system's reorganization plan announced in 2021, future teachers are only to be exclusively trained with the 4-year curriculum of a teacher's college. As a result, the preparation process for prospective teachers will naturally become more unitary, concentrated, and inflexible [14]. This reorganization will in turn presumably lead to a change in not only the preparedness but also the efficacy and job satisfaction of teachers [15,16]. Additionally, the correlation between teacher preparedness and job satisfaction is also a matter directly linked to the "transformative competence" pointed out by the OECD Future of Education and Skills 2030 [17]. Indeed, just as the OECD report clearly states, what transformative competence pursues is not only related to the well-being of the student; it is also intertwined with the well-being and the sustainability of the teacher him or herself. The more prepared a teacher is for the role of being a professional teacher, the more fit he or she becomes for the purpose of transformative competence: "creating new value, reconciling tensions and dilemmas, and taking responsibility" [17,18]. Based on these critical thoughts and needs, utilizing TALIS (Teaching and Learning International Survey), this study aims to explore the relationships between career motivation, preparedness, feelings of self-efficacy, and self-reported job satisfaction of current Korean teachers. The specific research questions are as follows.

First, does a relationship exist between the preparedness, job satisfaction, self-efficacy, and career motivation of teachers?

Second, do teacher self-efficacy and career motivation show a significant mediating effect between teacher preparedness and job satisfaction?

2. Theoretical Background

The improvement of teacher job satisfaction, teacher efficacy, and career motivation is linked with higher qualities and quantities of early teacher education [9–11]. Initial teacher education has been the subject of sustained reform and debate [19]. Initial teacher education is an intensive experience that requires teachers to be both learners and teachers, and due to this complexity, policymakers in all nations struggle to effectively structure initial teacher development initiatives. In this study, the relationship between teacher preparedness, teacher self-efficacy, teacher career motivation, and teacher job satisfaction was analyzed in detail so that it could be used as basic data for effective initial teacher education.

2.1. Teacher Preparedness

Preparing, which literally means "to make or get (someone or something) ready for something that will happen in the future", when combined with the teaching profession implies a period of "ready-ing" a teacher for change, as described in the transformative competence concept proposed by the OECD. The concept of preparedness differs from the verb "prepare" in that it indicates how well someone (e.g., a teacher) has already been prepared for something imminent [20]. Teacher preparedness cannot be separated from consideration of the purpose and curriculum of teacher education courses. This curriculum, as Darling-Hammond and Bransford (2007) point out, is determined and adjusted by the social group's expectations for teachers. Thus, teacher preparedness is an overall concept overlapping the manner, qualities, and ethics that our society sustainably requests of teachers and considers crucial for the teacher's success in the actual school [21].

In addition, teacher preparedness is connected to the standards of teacher competence required for performing professional duties, which include personal, pedagogic, professional, and social competencies. It also includes the mastery of knowledge, skills, values, and attitudes that are reflected in the habits of thinking and acting needed for carrying out the role of teacher [22]. Professional teachers are obliged to thoroughly plan and carry out a quality learning process, and assess and evaluate the outcomes of learning. In order to meet these obligations, the first step a teacher must take is to plan to learn, especially to compile a syllabus and a learning implementation plan [23]. Teacher preparedness is a clear indicator of how well and sustainably accustomed a teacher is to the roles and duties mentioned above.

2.2. Teacher Job Satisfaction

Job satisfaction is of course vital for the employee's sustainable well-being and retention, which are both especially essential for high-stress occupations, such as teaching. Job satisfaction can be defined as the affective orientation of individuals towards their roles in the jobs they do, and their feelings and attitudes towards their jobs [24]. In the field of education, since the teacher is the most important implementing entity for improving classes and managing the school, teacher job satisfaction needs to be regarded as a core determinant for enhancing the quality of education. The job satisfaction of the teacher is a sentiment evoked by a complex interaction between the job itself and its every surrounding factor, a feeling which greatly affects the performance of the teacher and could also provide an opportunity for an even deeper focus on education [25].

Teachers are expected to love their professions, maintain a positive attitude towards their jobs, be satisfied with what their professions bring, and have high self-efficacy beliefs, feeling that they can fulfill the duties inherent in their jobs [26]. In the case of TALIS, teacher job satisfaction comprises satisfaction with the profession itself—including the role and work of a teacher—and also with the school environment. The variables representing job satisfaction for Korean teachers were categorized as either teacher or school characteristics, with the latter including variables associated with school demographics and the school climate [27].

2.3. Teacher Self-Efficacy

Self-efficacy is a central concept of Bandura's (1986) social cognitive theory and is viewed as the foundation for human agency [28]. Self-efficacy is the belief that one can sustainably produce desired effects through one's actions, thus having the power to create change [29]. According to Bandura's theory, self-efficacy beliefs develop in response to four sources of information: enactive mastery experience, vicarious experience, verbal/social persuasion, and physiological and affective experience. The source that has the most powerful influence on self-efficacy is the "enactive experience", in which the feeling of self-efficacy for a particular behavior is increased by successfully and sustainably performing it.

A teacher's self-efficacy can be defined as the teacher's beliefs about his or her capability to teach a subject matter effectively to students and bring about desired outcomes in both student engagement and learning [30]. Cerit (2013) found that the teachers' level of self-efficacy regarding the students' engagement and instructional strategies was positively associated with their willingness to enact curriculum reform in their classrooms [31]. This discovery is echoed by Donnell and Gettinger (2015), who claimed that teachers' self-efficacy predicted their acceptance of a state-mandated reform agenda regarding the "Response to Intervention" (RTI) in the context of the US [32].

2.4. Teacher Career Motivation

Career motivation is a multidimensional construction consisting of elements such as career resilience, career insight, and career identity, and it determines the direction and strength of educational behavior [33,34]. An individual with higher motivation for a particular task or field displayed a higher effort level, persistency, and interest compared to others, and this disparity only grew wider when the individual faced difficulties concerning that matter [35].

The motivation for choosing and maintaining a teaching career is not any different. Thus, the teacher's career motivation corresponds to the amount of sustainable effort and the actual intensity of action that goes into the attempt to successfully fulfill the role of the teacher [36]. According to Huberman (1993), teacher career motivation can be divided into three parts: active motivation, passive motivation, and material motivation [37]. Of these subcategories, this study will emphasize active motivation, a concept that not only includes the intrinsic value of teaching, but also those concerning values such as social utility, the desire to share knowledge and influence with others. This is important because TALIS uses teacher career motivation based on social utility value as a major variable.

For reference, the OECD report (2019) states that the altruism of teaching shows a resemblance to the altruism of public service and the desire to increase social value in terms of its motivation [38]. Similarly, Perry et. al., (2010) also defined the motivation for teaching as a type of public motivation to do good for others and the society at large [39]. He/she asserts that this motivation promotes the sustainable participation and concentration of teachers in the teaching scene.

2.5. Relationships between Factors

Teacher self-efficacy has important implications for education since it "represents the teacher's belief in their ability to organize and execute necessary actions required to successfully carry out a specific educational task in a particular context" [40] (pp. 793–794). Teacher self-efficacy can change over time; it can be increased as well as decreased with the quantity and quality of teacher experience in educational institutions [41,42].

Additionally, teacher job satisfaction has been linked to feelings of teacher self-efficacy [43]. Teachers who view themselves as competent in their professions might have higher self-efficacy beliefs, which could reflect positively on their levels of job satisfaction [44]. As teachers find success in the classroom, their competency and self-efficacy grow. Studies about teacher self-efficacy also back up this concept, as veteran teachers tend to have higher levels of self-efficacy than novice teachers [45].

Studies implying the positive effects of teacher career motivation on teaching activities, commitment and the job satisfaction of the teacher have also been reported many times [46–50]. These considerations all support the idea that the career motivation of a teacher could also positively affect teachers' efforts to promote the educational motivation of students, execute new teaching methods, and sustainable reform education. In addition, going on the results of a study of the relationship between the career motivation and job satisfaction levels of teachers based on social utility values [51], not only can it be assumed that the teacher social utility value derived career motivation of elementary school teachers positively affects teacher job satisfaction, but also that its effect is larger compared to other variables such as teacher self-efficacy or the quality of teacher-student relationships.

In Korea, teaching is widely regarded as a relatively stable profession with quite reasonable pay and benefits; however, with the complexity and burden of the job intensifying, the retirement age is also becoming lower and lower. Job satisfaction is indeed important to the teacher from an individual perspective, but given its great impact on students, it is also crucial to thoroughly examine the relationship between teacher job satisfaction and preparedness from the teacher education level.

In this study, the research assumptions were specifically established based on the analysis results of previous studies on the relationship between variables. First, teacher preparedness will affect teacher self-efficacy, teacher career motivation, and teacher job satisfaction. Second, teacher self-efficacy and teacher career motivation will affect teacher job satisfaction. The research model constructed around the research assumption is as follows (Figure 1).

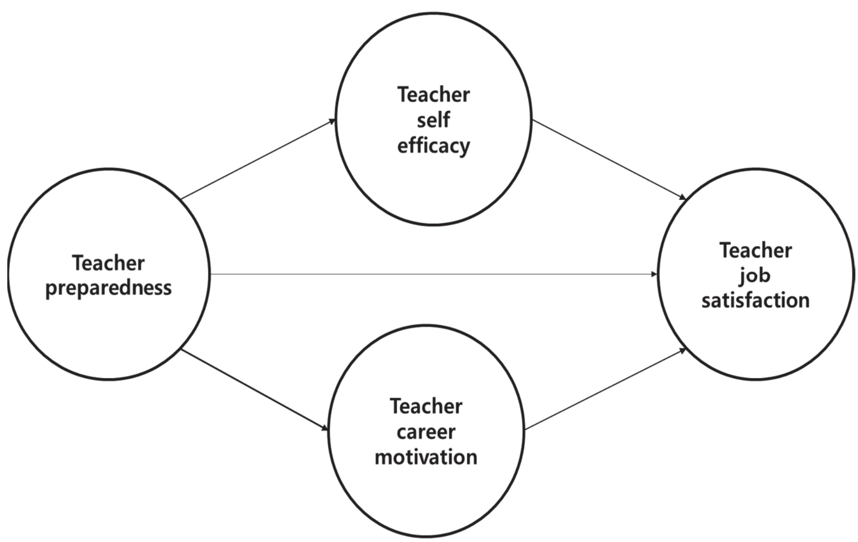

Figure 1. Research model of this study.

3. Methods

3.1. Data Collection and Sampling

Participants in this study included Korean middle school teachers. Data points used in this study were obtained from the 2018 Teaching and Learning International Survey (TALIS) conducted by the Organization for Economic Cooperation and Development (OECD). The latest international large-scale database which contains a nationally representative sample of teachers, TALIS 2018, was released for public use in June 2018. TALIS 2018 is an international survey that offered the opportunity for teachers and principals to provide input into education analysis and policy development. This data set was downloaded from https://www.oecd.org/education/talis/talis-2018-data.htm (accessed on 24 June 2022).

First, for this study, only full-time middle school teachers in Korea were selected from the 2018 TALIS data downloaded for this study. Second, teachers who answered all the questions of gender, age, educational background (highest level of formal education completed), and experiences as a teacher in total were selected. A total of 1266 teachers were used for the analysis of this study. The demographics of teachers in this study are displayed in Table 1.

Table 1. Sample Demographics.

Characteristics		**Percentage (%)**
Gender	Male	29.7
	Female	70.3
Age	20 s	8.1
	30 s	27.6
	40 s	30.6
	50 s	31.9
	60 s	1.8
Highest formal education level	ISCED 2011 Level 6	62.7
	ISCED 2011 Level 7	35.9
	ISCED 2011 Level 7	1.4
Experiences as a teacher in total	10 years or less	28.0
	11–20 years or less	30.0
	21–30 years or less	31.3
	31 years or more	10.7
Experiences as a teacher at this school	1 year or less	25.4
	2 years or less	19.1
	3 years or less	17.4
	4 years or less	15.8
	5 years or more	22.3

3.2. Research Variables and Instruments

All items in the survey instrument employed a 4-point Likert scale without a midpoint because the middle category was often over-selected by respondents when their opinions were not firm, reducing the reliability of the instrument [52]. In this study, 27 items were used. For the validity of this research instrument, confirmatory factor analysis was performed as the first stage of the two-stage approach structural equation model analysis. The Cronbach's alpha results demonstrated high reliability with $\alpha > 0.80$. Table 2 presents variables, measurement items, scales, and the Cronbach's α value for this study.

Table 2. Variables and Measurement Instrument.

Variables	Items	Scale	Cronbach'α
Teacher preparedness (what extent did you feel prepared for each element in your teachings)	Content of some or all subject(s) I teach Pedagogy of some or all subject(s) I teach General pedagogy Classroom practice in some or all subject(s) I teach Teaching in a mixed ability setting Teaching in a multicultural or multilingual setting Teaching cross-curricular skills Use of ICT Student behavior and classroom management Monitoring students' development and learning	1: Not at all 2: Some-what 3: Well 4: Very well	0.941
Teacher job satisfaction (how you generally feel about your jobs)	The advantages of being a teacher clearly outweigh the disadvantages If I could decide again, I would still choose to work as a teacher I regret that I decided to become a teacher * I wonder whether it would have been better to choose another profession * I think that the teaching profession is valued in society All in all, I am satisfied with my job	1: Strongly disagree 2: Disagree 3: Agree 4: Strongly agree	0.863
Teacher self-efficacy (what extent can you do the followings)	Get students to believe they can do well in school work Help students value learning Motivate students who show low interest in school work Make my expectations about student behavior clear Help students think critically Provide an alternative explanation, for example when students are confused Vary instructional strategies in my classroom Support student learning through the use of digital technology	1: Not at all 2: To some extent 3: Quite a bit 4: A lot	0.900
Teacher career motivation (How important were the following for you to become a teachers)	Teaching allowed me to influence the development of children and young people Teaching allowed me to benefit the socially disadvantaged Teaching allowed me to contribute to society	1: Not at all 2: low importance 3: moderate 4: high	0.846

Note. * was reverse-coded in the analysis.

3.3. Methods

The collected data were analyzed using SPSS 21.0 for Windows and AMOS 21.0, according to the following method. First, descriptive statistics and reliability analyses were performed on the demographic characteristics of the subjects to check the normality, reliability, and multicollinearity of the measurement variables. Second, after identifying a correlation, confirmatory factor analysis was performed according to the two-step approach proposed by Anderson and Gerbbing (1988) to estimate the validity of the structural equation model [53]. Third, bootstrapping was performed to verify the mediating effects of the final model, and phantom variables were used to verify the statistical significance of the individually mediated effects. Since the accuracy of bootstrapping increases with the number of estimates, the number of estimates was set to 10,000.

The fitness of the structural equation model was verified using the maximum likelihood method. χ^2, RMSEA was used for the absolute fit index; TLI and CFI were used for the incremental fit index. The acceptability of the model was evaluated based on the suggested cut-off values of 0.90 or higher for CFI and TLI [54,55], and 0.08 or lower for RMSEA [56].

4. Results

4.1. Descriptive Statistical Analysis

The skewness and kurtosis values of each variable were found to confirm the normality of the data, and the absolute values of both skewness and kurtosis of all variables were less than 3 and 8 respectively (Table 3). This satisfied the conditions of normal distribution [57]. To this end, the present study used Maximum Likelihood (ML) as the parameter estimation method and the bootstrapping approach for both CFA and SEM.

Table 3. Descriptive statistics.

Variables	Items	M	SD	Skewness	Kurtosis
Teacher preparedness	TP1	20.97	0.793	−0.231	−0.743
	TP2	20.92	0.808	−0.187	−0.747
	TP3	20.80	0.787	−0.012	−0.724
	TP4	20.90	0.802	−0.185	−0.698
	TP5	20.48	0.926	0.029	−0.845
	TP6	10.87	0.925	0.761	−0.417
	TP7	20.50	0.937	0.006	−0.880
	TP8	20.49	0.954	0.029	−0.928
	TP9	20.64	0.962	−0.178	−0.921
	TP10	20.56	0.934	−0.076	−0.865
Teacher job satisfaction	JS1	30.05	0.670	−0.494	0.667
	JS2	20.75	0.866	−0.253	−0.596
	JS3	30.06	0.770	−0.579	0.069
	JS4	20.71	0.850	−0.049	−0.730
	JS5	20.72	0.859	−0.266	−0.546
	JS6	30.07	0.639	−0.519	10.065
Teacher self-efficacy	SE1	30.22	0.653	−0.365	−0.276
	SE2	30.21	0.670	−0.433	−0.140
	SE3	20.82	0.758	−0.016	−0.637
	SE4	30.03	0.691	−0.230	−0.323
	SE5	20.96	0.709	−0.161	−0.446
	SE6	30.25	0.630	−0.402	0.077
	SE7	30.09	0.685	−0.220	−0.515
	SE8	20.94	0.779	−0.147	−0.775
Teacher's career motivation	CM1	30.32	0.694	−0.718	0.051
	CM2	20.95	0.856	−0.436	−0.506
	CM3	30.11	0.800	−0.594	−0.216

4.2. Confirmatory Factor Analysis and Structural Equation Modeling

Twenty-seven items were retained for model development using confirmatory factor analysis (Table 4). All factor models were tested with the structural equation modeling AMOS 21.0. The Chi-square 1680.357, degrees of freedom 306, NFI 0.927, CFI 0.940, TLI 0.931 and RMSEA 0.060. Based on these indices, the conceptual model exhibited a good fit for the data. Factor loadings were above 0.50 for all sub-factors and were statistically significant. The average variance extracted (AVE) ranged from 0.518 to 0.655 and thus met the standard (>0.50), and the construct reliability (CR) ranged from 0.755 to 0.859 and thus met the standard (>0.70), securing convergent validity.

Table 4. Confirmatory factor analysis.

Measured Variable		Latent Variable	B	β	S.E.	C.R.	AVE	CR
TP10	←	TP	10.000	0.849				
TP9	←	TP	0.959	0.790	0.022	440.570 ***		
TP8	←	TP	0.859	0.714	0.030	290.110 ***		
TP7	←	TP	0.958	0.811	0.027	350.304 ***		
TP6	←	TP	0.675	0.578	0.031	220.011 ***		
TP5	←	TP	0.971	0.831	0.026	360.820 ***	0.612	0.859
TP4	←	TP	0.871	0.860	0.022	380.915 ***		
TP3	←	TP	0.752	0.757	0.024	310.614 ***		
TP2	←	TP	0.842	0.826	0.023	360.462 ***		
TP1	←	TP	0.763	0.762	0.024	320.073 ***		
JS4	←	JS	10.000	0.695				
JS6	←	JS	0.859	0.794	0.035	240.517 ***		
JS5	←	JS	0.812	0.559	0.046	170.618 ***		
JS2	←	JS	10.220	0.833	0.050	240.329 ***	0.518	0.792
JS1	←	JS	0.862	0.760	0.038	220.407 ***		
JS3	←	JS	0.837	0.642	0.031	270.116 ***		
SE1	←	SE	10.000	0.703				
SE2	←	SE	10.099	0.752	0.030	360.074 ***		
SE3	←	SE	10.257	0.761	0.051	240.723 ***		
SE4	←	SE	0.970	0.572	0.052	180.715 ***		
SE5	←	SE	10.243	0.826	0.047	260.411 ***	0.525	0.755
SE6	←	SE	10.143	0.740	0.048	230.768 ***		
SE7	←	SE	0.975	0.710	0.042	230.211 ***		
SE8	←	SE	10.055	0.707	0.046	230.106 ***		
CM3	←	CM	10.000	0.869				
CM2	←	CM	0.995	0.809	0.033	290.905 ***	0.655	0.794
CM1	←	CM	0.744	0.745	0.027	270.823 ***		

*** $p < 0.001$, Abbreviations: TP, Teacher preparedness; JS, Teacher job satisfaction; SE, Teacher self-efficacy; CM, Teacher's career motivation.

Table 5 displays the results of the structural equation model analysis performed to examine the pathways among teacher preparedness, job satisfaction, self-efficacy and a teacher's career motivation. The fit of the structural equation model was fairly robust (Chi-square 1732.158, degrees of freedom 307, NFI 0.925, CFI 0.937, TLI 0.928 and RMSEA 0.059).

Table 5. Structural equation model analysis.

Path			B	β	S0.E0.	C0.R0.	p
teacher self-efficacy	←	teacher preparedness	0.256	0.441	0.018	130.826	***
teacher career motivation	←	teacher preparedness	0.333	0.381	0.027	120.380	***
teacher job satisfaction	←	teacher preparedness	0.001	0.002	0.028	0.044	0.965
teacher job satisfaction	←	teacher self-efficacy	0.179	0.140	0.046	30.905	***
teacher job satisfaction	←	teacher career motivation	0.185	0.219	0.030	60.140	***

*** $p < 0.001$.

The structural equation model analysis result was as follows (Figure 2): First, teacher preparedness was significantly and positively affected by teachers' self-efficacy and career motivation levels. But teacher preparedness was not significantly affected by the teachers' job satisfaction. Therefore, teacher preparedness had no statistically significant direct effect on job satisfaction, only an indirect effect. On the other hand, teachers' self-efficacy and career motivation were significantly and positively connected with teachers' job satisfaction levels.

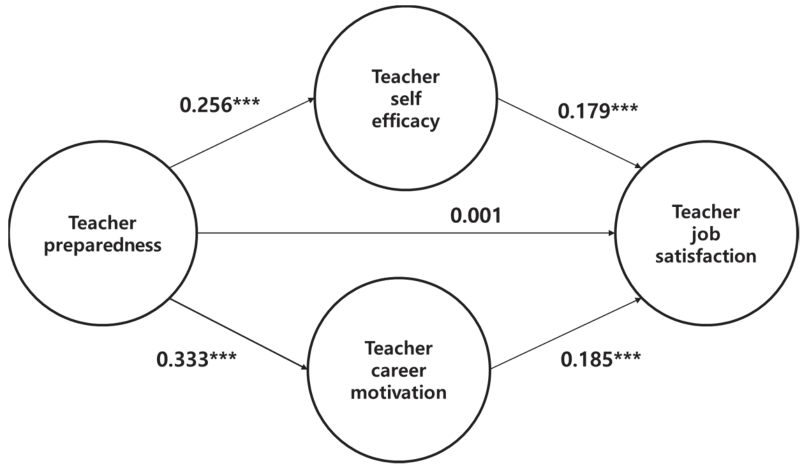

Figure 2. Results of the structural equation modeling analysis. (*** Significant at 0.001 level for regression coefficient).

4.3. Mediating Effect Using Phantom Models

In models that involve mediation effects, AMOS 21 provides bootstrap estimates, SE, and confidence intervals only for the total indirect effects (the sum of all specific indirect effects) [58]. Therefore, the phantom model approach, which provides the above information for specific indirect effects, was also employed [59,60]. The phantom model (Figure 3) enables the researcher to conduct robust tests of specific mediation hypotheses based on bootstrap procedures within a conventional covariance structure framework [61]. We created the phantom model, consisting of two phantom variables (P1, P2) and two direct paths. Then, equality constraints, denoted as a and b for the paths from teacher preparedness to teacher self-efficacy as well as from teacher self-efficacy to teacher job satisfaction are imposed between path coefficients. In the same way, p3 and p4 were created, and c and d were inserted into the coefficients.

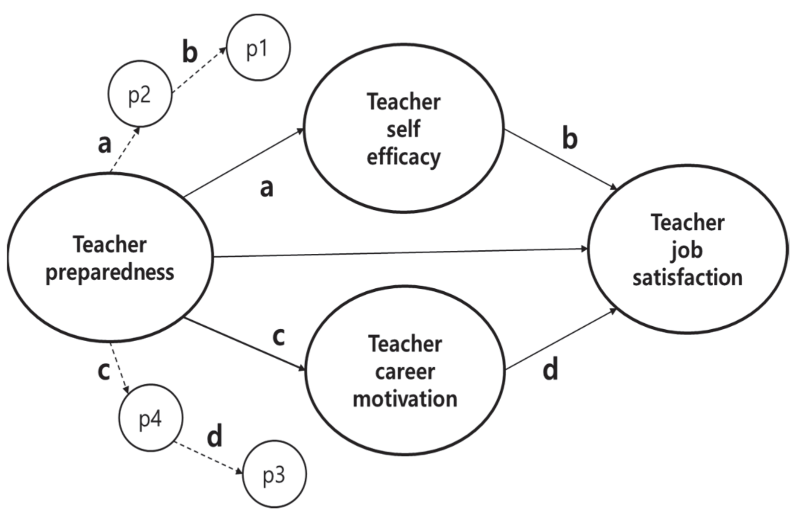

Figure 3. SEM and the phantom model.

The results of mediating effects of the two personal factors, teacher self-efficacy, and career motivation, on the relationships between teacher preparedness and job satisfaction are presented in Table 6. Of the possible paths, the following were found to be statistically significant:

Table 6. Results of the mediation model using the phantom model approach.

Effect	Estimate	SE	95% Confidence Interval	*p*	Bootstrap M	Bootstrap SD
teacher self-efficacy ← Teacher preparedness	0.256	0.018	(0.215, 0.293)	0.009	0.255	0.001
Teacher career motivation ← Teacher preparedness	0.333	0.027	(0.277, 0.388)	0.009	0.333	0.002

First, teacher self-efficacy had significantly and positively mediating effects on teacher preparedness (indirect effect: 0.256, $p < 0.01$). Second, teacher career motivation had significantly and positively mediating effects on teacher preparedness (indirect effect: 0.333, $p < 0.01$). In conclusion, teacher self-efficacy and teacher career motivation had statistically significant mediating roles between teacher preparedness and teacher job satisfaction. Based on the estimate of mediating effects, it was found that teacher career motivation had a greater positive effect than teacher self-efficacy. The results of the test for mediating effects are shown in Table 6.

5. Discussion and Suggestion

This study utilizes the 2018 TALIS (Teaching and Learning International Survey) conducted by the OECD to analyze the effect of teacher preparedness in Korean teachers on their levels of job satisfaction and the meditation effects of teacher self-efficacy and career motivation within that relationship. The main results are as follows.

First, the preparedness of teachers did not have a statistically significant direct effect on teacher job satisfaction. The variables that did have a statistically significant effect were teacher self-efficacy and career motivation, which both affected teacher job satisfaction positively. This shows that teachers with high self-efficacy and career motivation had a higher and more sustainable level of job satisfaction. The positive impact of teacher self-efficacy and motivation on job satisfaction is widely supported in the literature [26,32,41]. Meanwhile, teacher preparedness was revealed to have a statistically significant positive effect on teacher self-efficacy and career motivation. This means that teachers who were well prepared at the teacher education level were able to have a higher level of self-efficacy and career motivation. Prior studies also portrayed a similar result [62].

Second, the statistically significant influence relationship is as follows. teacher preparedness had a bigger effect on teacher career motivation than that on self-efficacy. At the same time, teacher self-efficacy and career motivation had a positive effect on teacher job satisfaction, with the latter outweighing the former in terms of impact. Thus, it can be concluded that the importance of teacher career motivation is larger in the relationship between teacher preparedness and job satisfaction.

The TALIS 2018 revised and expanded on the topic of teacher motivation. The topic itself, for the most part, has been joined with career choice and job satisfaction [63]. This shows that the OECD is also showing attention to teacher career motivation. A similar conclusion had already been gained from a prior study using the TALIS of OECD countries. Thus, teacher motivations change throughout a teacher's career, which relates to initial teacher preparation, self-efficacy, and other teacher characteristics [64]. The findings regarding motivations in particular revealed that teachers scored high on social utility value as an important motivation to become a teacher [63,64].

Third, a mediation effect analysis using phantom variables was conducted to take a closer look into the mediation effects of teacher self-efficacy and career motivation in the relationship between teacher preparedness and job satisfaction. According to the result, the mediation effects of teacher career motivation outweighed that of teacher self-efficacy.

Based on the results above, we wish to make the following suggestions concerning the sustainable enhancement of teacher preparedness, self-efficacy, career motivation, and job satisfaction in the teacher education course.

The first finding of this study shows that the variables directly affecting teacher job satisfaction levels were efficacy and career motives. Therefore, we need to actively seek out the means for boosting teacher self-efficacy and career motivation. These measures should not only be sought from the level of current teachers, but also at the student-teacher level. For example, the system needs to be reorganized by further valuing the Teaching Personality and Aptitude Test and strengthening in-depth interviews when selecting student teachers for entrants with a greater motivation towards the teaching profession in preference to those with just higher grades. In addition, sustainable teacher education programs also need to be redesigned by actively opening programs connected to the actual teaching scene, for higher understanding and more specific realizations regarding the importance of duty in the teaching profession.

Second, the first and second finding of this study reveals that teacher efficacy is an important factor in improving teacher job satisfaction. A positive sense of teacher self-efficacy can be formed and further enhanced when teaching competency is sufficiently guaranteed through teaching experiences such as simulated instruction activities and peer supervision. In this manner, it is exceedingly important that the opportunity of simulated instruction be sufficiently provided for student teachers who naturally lack first-hand teaching experience [65]. Especially when it comes to teacher education courses in Korea, it is necessary that teacher self-efficacy be promoted and teacher motivation is improved by means of expanding the sustainable opportunities for simulated instructions and peer supervision activities.

Third, this study shows that teachers who were well prepared at the teacher education level showed high self-efficacy and career motivation. Therefore, the target level of teacher education needs to be set higher than the current teacher education course. The profession of teaching is open to everyone, but that does not mean that anyone could successfully fulfill the job. The profession can only be successfully fulfilled when the practical capability gained by teacher education training is imposed on top of the internalization of the required personality, creativity, sociality, and ethics. The teacher should be more than a mere messenger of knowledge; the teacher should be able to supervise and guide teaching activities of various levels as a facilitator of promoting students' learning and as a fully capable research mentor [66]. These capabilities are prepared in the teacher preparation institution and should be strengthened with in-service education systems after employment. From this view, the merely four-week teaching practicum in Korea needs to be revamped both in quantity and quality. At least in quantity, a system improvement should be devised by examining the pros and cons of the German teacher practicum system, which generally takes 1 to 1.5 years [67].

Fourth, the second and third findings imply that we need to pay more attention to the role and importance of teacher career motivation. Teacher career motivation is connected with professional values and the identity of teachers. Therefore, systematic teaching profession counseling should probably be carried out in the initial teacher education stage. Though the creation of teacher identity is indeed a core objective of teacher training which should be fulfilled through the curriculum, it is also a matter that should be supplemented and updated through non-subject educational programs or non-curriculum activities. Additionally, it should be approached carefully through individualized guidance and counseling. The reason for this is that though teacher identity may be identified and analyzed as a sort of collective identity depending on the degree of academic interest, the identity of the teacher in the actual classroom is still created, performed, and functioned at the individual level. Therefore, it is exceedingly important that a sophisticated system be established for helping the creation and development of the teacher's motivation and identity as an individual, starting from the teacher training process.

6. Conclusions

This study explored the relationship between teacher preparedness and job satisfaction by utilizing data from the OECD 2018 TALIS and it also analyzed the mediating effect of teacher self-efficacy and motivation. According to this study, preparedness affects the job satisfaction of teachers, and teacher self-efficacy and motivation show an important mediating effect in that process. Therefore, to enhance the sustainable job satisfaction of teachers, specific measures for enhancing the teacher preparedness, self-efficacy and motivation should be sought out. Additionally, these efforts and institutional complements should not only be targeted toward current teachers but should be actively planned and implemented from the teacher training level.

In the case of Korea, a Development Plan for Elementary and Middle School Teacher Training Systems (Ministry of Education, 2021) has been announced, and further discussions concerning the matter are expected to accelerate in the future [68]. This plan aims the support student growth, convergence classes, class innovations for future competency development, curriculum restructuring, guaranteeing basic academic ability, counseling, and support for students in crisis, communication and cooperation, and school innovation. Yet, teachers are still and always will be the key to the realization of these goals. These teachers should be nurtured into those sufficiently prepared and motivated with high self-efficacy through the sustainable teacher training process. All in all, a more efficient direction and better measures need to be introduced through comparative studies of countries with similar teacher training systems as Korea.

Education is the foundation of a society and the key to a sustainable future. And that education starts with teacher education. Cultivating prepared teachers, teachers with high self-efficacy, motivated teachers, and teachers with high self-satisfaction is the essential and surest way not only for the well-being of teachers but also for a sustainable society. Through this study, we reconfirmed the meaning of teacher education by examining the interface between a sustainable society and teacher education and suggested the direction of teacher education for a sustainable common future.

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Article

Students' Environmental Care Attitude: A Study at Adiwiyata Public High School Based on the New Ecological Paradigm (NEP)

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Abstract: Environmental care attitude is an important factor in protecting the environment. The Adiwiyata Award is presented as the highest recognition for implementing an environmental care attitude. The aims of this study are to (1) evaluate the execution of the environmental curriculum in Adiwiyata schools; (2) to analyze the students' environmental care attitudes in Adiwiyata schools in the Pati Regency using the new ecological paradigm (NEP) scale; and (3) to examine the students' environmental care attitudes in Adiwiyata schools in the Pati Regency related to gender differences. Based on the criteria of Adiwiyata schools, they were used as research subjects. The research subjects were chosen using a purposive sampling technique. A questionnaire was utilized as a data collection instrument. The new ecological paradigm (NEP) scale was used to assess environmental care attitudes. This study used a Likert scale to assess environmental care attitudes. The Mann-Whitney test was used to identify gender differences in environmental care attitudes. The results found that (1) Adiwiyata schools in the Pati Regency supported the implementation of environmental education in the curriculum, as well as participation in environmental activity programs and the use of greenhouses; (2) the environmental care attitudes of students from the SMA Negeri Pati Regency were in the moderate category; and (3) there was a gender difference based on environmental care attitudes, which found that female students have a higher environmental care attitude than the male students. Environmental education plays an important role in gender differences because the Adiwiyata school has integrated learning activities with the environmental education curriculum, and participatory-based environmental activities can improve students' environmental care attitudes. The potential implication for policy and practice in the field is that humans will consciously prevent environmental problems from occurring.

Keywords: environmental care attitude; Adiwiyata; new ecological paradigm; environmental education

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1. Introduction

Environmental problems caused by human behavior—that is, those less concerned with the environment—cause environmental pollution [1,2]. One cause of environmental problems that can contribute to environmental damage is humans who do not feel responsible for the environment, whether it be because they do not care about the environment or because they do not want to take part in protecting and preserving it. Environmental problems might occur because individuals still have a low level of environmental ethics and environmental care attitudes [3], resulting in environmental problems such as river pollution [4], waste pollution [5], floods [6–8], industrial waste pollution [9–11], forest degradation [12], seawater pollution [13], and drought [14]. All environmental problems have the potential to impact environmental quality [15] and even climate change [16].

The community's participation in environmental maintenance and management in the Pati Regency is still ineffective, resulting in pollution. Based on data and information from the Environment Agency in the Pati Regency, it has been discovered that 95 tons of inorganic waste were produced, which were stockpiled in the landfill (Tempat Pembuangan Akhir Sampah–TPA) in Sukohajo Village, Margorejo District, Pati Regency [17]. This inefficient environmental management results in waste pollution [11]. Environmental pollution can be prevented by reducing the quantity of waste produced (reduce), reusing it for the same purpose (reuse), and recycling it (recycle) [18,19]. For instance, reducing materials that are difficult to decompose, or that degrade quickly, and instead using unused waste can help reduce waste pollution. Meanwhile, recycling allows waste, which is frequently perceived as being useless, to be put to new use.

Through environmental education, it is also possible to influence human behavior that is less careful with the environment [20–22]. The Adiwiyata school curriculum includes environmental education with the aim of establishing a school that is cultured and cares about the environment [23,24]. This is supported by the Minister of Environment's Regulation No. 5 of 2013 regarding the Guidelines for the Implementation of the Adiwiyata Program, where the Adiwiyata School is a program that engages all stakeholders in schools and the community to increase students' environmental care attitudes. Environmental sensitivity is a fundamental mindset that must be developed in all school members [25,26]. Environmental care attitudes can be found in communities that share the same goals and values. School members who want to preserve the school environment are expected to be leaders in establishing a clean and comfortable environment, as well as promoting environmental care attitudes on a larger scale, particularly in the community. Individuals with a high environmental care attitude are able to anticipate global environmental issues that have emerged in recent years [27,28].

Environmental care attitudes must be implemented early on in future generations in order to establish positive habits for the younger generation [29,30]. Various studies have been conducted to investigate the importance of environmental care attitudes in education, such as the students' environmental care attitudes at the Ar-Rohmah Islamic Boarding School in Malang, which are still considered low [31]. Furthermore, in Pekanbaru, some students are found to be littering trash in the schoolyard [32]. It was also discovered that students in the Pati Regency littered, as evidenced by the scattered trash in the schoolyard [33].

Environmental care attitudes are necessary for resolving environmental issues and promoting a nice and clean environment [34]. Environmental care attitude is measured using the new ecological paradigm (NEP) scale, which has five components: (1) limits to growth; (2) anti-anthropocentrism; (3) balance of nature; (4) anti-exemptionalism; and (5) eco-crisis [35,36]. The new ecological paradigm (NEP) scale is used to measure environmental care attitudes due to its advantages, such as being viewed as a credible data collection tool to determine environmental care attitudes, and it is frequently used as a measurement instrument in different countries [35,37,38]. According to research conducted in Greece, the new ecological paradigm (NEP) scale has the consistency to assess gender differences based on environmental care attitudes [39,40]. Moreover, research conducted in Brazil revealed that the new ecological paradigm (NEP) scale has been demonstrated to be a valid instrument for measuring environmental care attitudes [41].

Indicators in the new ecological paradigm (NEP) are suitable for assessing environmental care attitudes. Indicators of limits to growth can be used to determine human environmental knowledge and attitudes. Furthermore, indicators of anti-anthropocentrism can be used to identify humans' roles in using natural resources and the environment. Indicators of the balance of nature can determine behavior in balancing environmental sustainability. An indicator of anti-exemptionalism is a sense of responsibility for regulating and using the environment. Indicators of eco-crisis can determine behavior in preventing environmental damage.

Gender differences in the perception of environmental care attitudes are one of the issues that are emerging [42,43]. Moreover, gender socialization theory demonstrates that environmental care attitudes are determined by the socialization process shaped by a particular gender's cultural norms [44]. According to these findings, there are differences between men and women. Women are more empathetic, cooperative, and willing to assist than men [45]. Men have courageous personalities, enjoy challenges and competition, and are communicative, so they enjoy discussing ideas in online forums [46].

Therefore, the following objectives are investigated in this study: (1) to evaluate the implementation of the environmental curriculum in Adiwiyata schools; (2) to analyze students' environmental care attitudes in Adiwiyata schools in the Pati Regency using the new ecological paradigm (NEP) scale; and (3) to examine students' environmental care attitudes in Adiwiyata schools in the Pati Regency related to gender differences. Research on students' environmental care attitudes in the Pati Regency is expected to be one of the references for implementing environmental education in schools.

2. Materials and Methods

The aims of this research are: (1) to evaluate the implementation of the environmental curriculum in Adiwiyata schools; (2) to analyze students' environmental care attitudes in Adiwiyata schools in the Pati Regency using the new ecological paradigm (NEP) scale; and (3) to examine students' environmental care attitudes related to gender differences in Adiwiyata schools in the Pati Regency. Students' environmental care attitudes are assessed using survey techniques and questionnaires as data collecting instruments. Research subjects were selected using a purposive sampling technique (Table 1). Three Adiwiyata Public High Schools in the Pati Regency were chosen as research subjects: SMA Negeri 1 Pati, SMA Negeri 2 Pati, and SMA Negeri 3 Pati. Research references are used to determine research locations based on the frequency of environmental issues in the school environment. In addition, the research location was determined based on the focus or topic of the Adiwiyata school. The research subjects were selected using a purposive sampling technique and divided into two groups based on the average score of student learning outcomes. Research locations with two or more classes will make it easier for researchers to choose research subjects. The criteria were used to determine research subjects in terms of the average value of high and low learning outcomes. Of the two research classes that were selected, it was determined that the first class was the class that had the highest average learning outcomes, and the second class was the class that had the low average learning outcomes. The sample in terms of gender was determined by gender status within two classes that were selected as research subjects.

Table 1. Research Subject.

No	School Name	Class	Total Student
1	SMA Negeri 1 Pati	XI IPS 1	30
		XI IPS 2	30
2	SMA Negeri 2 Pati	XI IPS 4	30
		XI IPS 2	30
3	SMA Negeri 3 Pati	XI IPS 3	30
		XI IPS 1	30
	Total		180

Source: (Primary Data).

A questionnaire was used to collect data for this research. For this research, students were given several written statements. The assessment of environmental care attitudes is based on a Likert scale with four response options: strongly agree (SA), agree (A), disagree (D), and strongly disagree (SD) (Table 2). Questionnaires were used to identify students' environmental care attitudes and were constructed with statements related to environmental care attitudes toward their school environment. Respondents were instructed to write a checkmark (√) next to one of the four alternative answers.

Table 2. Likert scale and knowledge score for environmental care attitude.

No	Category	Score
1	Strongly agree	4
2	Agree	3
3	Disagree	2
4	Strongly disagree	1

Source: (Sugiyono, 2013 [47]).

This study measures environmental care attitudes based on the new ecological paradigm (NEP) scale, which consists of five aspects: (1) limits to growth to determine human knowledge of environmental care attitudes; (2) anti-anthropocentrism to determine the role of humans in the utilization of natural resources and the environment; (3) balance of nature to determine behavior in balancing environmental sustainability; (4) anti-exemptionalism to determine the sense of responsibility for managing the environment and utilizing the environment; and (5) eco-crisis to determine behavior in preventing environmental damage [35,36].

The research instrument was tested on 40 students to determine the validity and reliability of the environmental care attitude questionnaire. To ensure the new ecological paradigm (NEP) questionnaire has valid and reliable values, the researchers took the Pearson correlation validity test and Cronbach's alpha reliability test with the Windows version of SPSS 22. The validity of the new ecological paradigm (NEP) questionnaire is determined based on the validity value of the r count > r table. The determination of the r table is based on the number of respondents, namely 40 students, which means that the r table has a value of 0.312 [48]. Table 3 shows that the new ecological paradigm (NEP) questionnaire has a value of r count > r table = 0.312. The Pearson correlation validity test results show that the new ecological paradigm (NEP) instrument is proven valid and can be used to obtain data on environmental care attitudes. The results of the validity and reliability tests of the environmental care attitudes questionnaire are shown in the following Table 3.

Table 3. Results of validity and reliability test of the environmental care attitude.

Indicator	Statement	P (2-Tails)	r	Cronbach's Alpha
Limits to growth	NEP 1: The number of humans that exist today exceeds the earth's carrying capacity.	0.000	0.688	0.724
	NEP 6: Earth has a lot of natural resources if humans are able to figure out how to use them.	0.000	0.875	
	NEP 11: Earth has limited space and natural resources.	0.000	0.854	
Anti-anthropocentrism	NEP 2: Humans have the right to manage the natural environment according to their needs.	0.000	0.816	0.746
	NEP 7: Plants and animals have the same rights as humans to survive.	0.000	0.767	
	NEP 12: Humans have overused natural resources.	0.000	0.500	
Balance of nature	NEP 3: Human actions can sometimes lead to natural disasters.	0.000	0.739	0.739
	NEP 8: The natural environment will not be disturbed by industry activities.	0.000	0.757	
	NEP 13: The environment is very vulnerable and easily disturbed.	0.000	0.734	

Table 3. *Cont.*

Indicator	Statement	P (2-Tails)	r	Cronbach's Alpha
Anti-exemptionalism	NEP 4: For individuals who have knowledge about the environment, it can be determined that they can protect it properly.	0.000	0.658	0.779
	NEP 9: Even though humans have special abilities, they will not be separated from the laws of nature.	0.000	0.794	
	NEP 14: By studying environmental science, we can preserve nature.	0.000	0.688	
Eco-crisis	NEP 5: Many humans take harmful actions against the environment.	0.000	0.734	0.756
	NEP 10: The current environmental crisis is exaggerated.	0.000	0.861	
	NEP 15: If this environmental problem continues, we will soon experience a major natural disaster.	0.000	0.778	

The reliability of the new ecological paradigm (NEP) questionnaire was determined based on Cronbach's alpha > r table [48]. Decision-making on reliability using Cronbach's alpha reliability coefficient criteria (1) very high (0.80–1.00), (2) high (0.60–0.79), (3) sufficient (0.040–0.59), (4) low (0.20–0.39), and (5) very low (0.00–0.19) [49]. The questionnaire is declared reliable if the reliability coefficient of Cronbach's alpha is > 0.60. Table 3 shows that each indicator from the new ecological paradigm (NEP) has a Cronbach's alpha m and has a Cronbach's alpha reliability coefficient value > 0.60. This analysis shows that the environmental care attitude instrument is reliable, and each new ecological paradigm (NEP) indicator includes a high Cronbach's alpha reliability coefficient. The data analysis step is carried out after the environmental care attitudes instrument has been proven to be valid and reliable. The measurement uses a variety of scores to determine environmental care attitudes, which are then analyzed using the percentage formula [50,51] (Table 4).

$$\text{Range}: \ \frac{The\ highest\ score - lowest\ score}{The\ number\ of\ values}$$

$$\text{Percentage}: \ \text{NP} \ = \frac{n}{sm} \times 100\%$$

where:

- NP = percentage
- n = observation results
- sm = maximum score

Source: [50].

Table 4. Criteria of environmental care attitude.

Score	Percentage	Description
50–60	81.68–100%	High EC
38–49	61.68–81.67%	Moderate EC
27–37	43.34–61.67%	Low EC
15–26	25.00–43.33%	Very Low EC

Source: (Arikunto, 2010 [49]).

The Mann-Whitney test was used to identify gender differences because the data was not normal (p 0.000 < p 0.05). The Mann-Whitney test is one of the most effective nonparametric tests, with high probability and statistically significant results [52]. Quantitative data analysis was performed using the SPSS application version 22 for Windows.

3. Results

3.1. Implementation of the Environmental Curriculum at the Adiwiyata School

Education is one of the most influential factors in an individual's environmental care attitude [53,54]. It is expected that individuals who have a high environmental care attitude will respect more about the environment. According to research, knowledge has a long-term impact on human neural function [55]. Integrating environmental education into Adiwiyata schools is a strategy for fostering environmental care attitudes [56]. The Adiwiyata program aims to establish in all school members, especially students, a commitment to environmental protection and sustainable development. The implementation of Adiwiyata schools is founded on three principles: educative, collaborative, and sustainable.

According to the findings of this research, the curriculum used by public high schools in Pati Regency is usually integrated with environmental education. The curriculum integrated with environmental education has activity points or educational vision and mission linked to concern for the environment. The Education Office has a policy that gives schools with Adiwiyata achievements the responsibility of implementing an environmental education curriculum. The implementation of the educational curriculum has also been discovered in India [57]; in Germany, it is related to the implementation of the environmental education curriculum to solve environmental problems [58]; and in Sweden which implements the educational curriculum to overcome the development trend of environmental culture and environmental education [59]. The preparation of an environmental education curriculum is not significantly different from other curricula; however, it must be adapted to content that can be integrated with the environment. The implementation of an environmental education curriculum has been incorporated into all subjects at Adiwiyata schools in the Pati Regency, but only a few materials can be integrated within this curriculum.

Adiwiyata Public High Schools in the Pati Regency have greenhouses for plant cultivation and student study materials. Having a greenhouse in a school is a great way to foster student interest and involvement in the environment. Cultivating plants in the school environment can be the first step in indirectly teaching students the significance of environmental protection. A school greenhouse can provide a platform for students to share their unique perspectives on vegetation within the classroom. Greenhouses are used at Adiwiyata Senior High School in the Pati Regency as a means of controlling the balance of climatic conditions and the intensity of temperature in the school environment.

Figure 1 shows the unique features of the greenhouse at Adiwiyata High School in the Pati Regency. It was found that (a) the greenhouse at SMA Negeri 1 Pati contains ornamental plants, horticultural plants, and medicinal plants, and there is a daily schedule for students to carry out plant cultivation and maintenance; (b) the greenhouse at SMA Negeri 2 Pati has a garden that is named "Learning Park", where students can carry out activities that can support environmental care attitudes, such as planting various types of plants and studying plant characteristics related to environmental protection and restoration; (c) the greenhouse at SMA Negeri 3 Pati focuses on cultivating horticultural crops. Horticultural crops that are cultivated in a greenhouse system can be an area for students who want to learn about cultivation. The greenhouse owned by SMA Negeri 3 Pati is known as the "horticultural area", and its purpose is to educate school members, particularly students, on plant cultivation, recreation, and research.

Adiwiyata Public High School in the Pati Regency engages in environmental protection and problem resolution. Participation of all school members, particularly students, in environmental activities, is based on participation aimed at improving students' environmental care attitudes [30]. Environmental participation can be in the form of habituation, example, and guidance that is integrated into learning or through routine activities. This is similar to previous research indicating that students' environmental care attitude will increase when faced with actual environmental problems [60,61].

Figure 1. Green House at Adiwiyata High School, Pati Regency. (**a**) Green House at SMA Negeri 1 Pati; (**b**) Green House at SMA Negeri 2 Pati; (**c**) Green House at SMA Negeri 3 Pati.

The Adiwiyata school program can be implemented through environmental activities based on participation, namely by creating programs or activities that focus on environmental management, implementing policies that are based on environmental care values, and implementing ideas that are suitable for school conditions and innovating to support the government's efforts to preserve the environment [62]. Environmental activities based on participation involve all parties, internally (principals, teachers, and school staff) and externally (students, parents, local community, government, and school partners). The Adiwiyata School formed a special team to conduct environmental activities based on participation by including teachers in the working group. The special team then creates a structured plan to organize an environmental activities schedule based on participation. The teacher serves as a facilitator and provides students with the motivation to present themselves [63]. Environmental activities based on participation can involve external parties (students, parents, surrounding communities, government, and school partners) by building partnership activities so that environmental action activities can be carried out to initiate the development of environmental education in schools following the times and following sustainable development principles [64]. Environmental activities based on participation are carried out through mutually beneficial cooperation of all parties—the school community, the surrounding community, and the environment—to achieve the common goals that have been planned.

Figure 2 shows the various activities planned by Adiwiyata schools, Pati Regency. It was found that (a) SMA Negeri 1 Pati has an activity program named "planting trees, planting kindness", which is carried out at the beginning of each new school year. The program aims to introduce and educate students on the importance of environmental preservation; (b) SMA Negeri 2 Pati has a program called the "plastic waste reduction movement". The program aims to reduce the use of plastic in schools by requiring students to bring their own drink bottles and by prohibiting the use of plastic in school canteens; (c) SMA Negeri 3 Pati has unused land that has been converted into a mini forest where teachers can teach students about biodiversity. In addition, the mini forest serves an important role in enhancing the school's air, allowing it to regulate the school's climate balance.

Figure 2. Environmental activities based on participation. (**a**) Planting trees program; (**b**) Plastic waste reduction movement; (**c**) Mini Forest.

3.2. Student's Environmental Care Attitudes Based on New Ecological Paradigm (NEP) Scale

This study analyzed students' environmental care attitudes at SMA Negeri 1 Pati, SMA Negeri 2 Pati, and SMA Negeri 3 Pati. The selection of the three research subjects was based on the criteria of an Adiwiyata school, where an Adiwiyata school is a type of school that prioritizes environmental protection and is cultured towards the environment. The research location is determined based on the level of environmental problems [11,65,66]. The research results related to students' environmental care attitudes at SMA Negeri Pati Regency can be seen in Table 5.

Table 5. Data of environmental care attitude of Adiwiyata Public High School in Pati Regency.

No	Indicator	Frequency				Total	Index of Environmental Care Attitudes	Category
		High	Middle	Low	Very Low			
1	Limits to growth	47	76	34	23		68.10	Moderate
2	Anti anthropocentrism	16	101	62	1		65.87	Moderate
3	Balance of nature	51	96	25	8	180	72.77	Moderate
4	Anti-exemptionalism	37	109	25	9		69.95	Moderate
5	Eco-crisis	56	79	34	11		71.66	Moderate
Index of Environmental Care Attitudes							69.67	Moderate

Based on the results of the study, it was found that all indicators of environmental care attitudes were included in the moderate category with a total percentage of 69.67%. The average value on the indicators of limits to growth, anti-anthropocentrism, anti-exemptionalism, and eco-crisis is included in the moderate category and receives the lowest score compared to other indicators. Further, it can be seen that the indicator of the balance of nature is higher than the other indicators.

In the indicator of limits to growth, there are beliefs that natural resources on Earth have limited volumes [35]. Some students do not understand how to use natural resources properly and are not able to understand the concept of natural resources on Earth or give examples of the proper use of natural resources. Research conducted in Indonesia found that increasing knowledge about the use of natural resources can be accomplished with several activities, namely planning, organizing, actuating, and controlling [67].

In the indicator of anti-anthropocentrism, there is a belief that humans have a role in utilizing natural resources and the environment [35]. Some students lack knowledge in natural resource management, environmental conservation, and environmental ethics. Some students were unable to provide examples of environmental issues and the practical implementation of environmental management. Following previous research on enhancing environmental ethics through conservation efforts, it was demonstrated that humans can respect the environment through tree cultivation [53].

In the indicator of anti-exemptionalism, there is a belief that humans have a responsibility to protect and manage the environment [35]. Some students lack a clear understanding of the concept of environmental preservation and are unable to provide concrete examples of how to preserve nature in their respective environments. Findings on anti-exemptionism indicators are supported by research from Thomas F. Homer-Dixon that scarcity and changes in renewable resources are the results of the irresponsibility of human beings in carrying the environment [68]. According to the Homer-Dixon theory, the importance of human responsibility is to preserve and manage the environment appropriately, because environmental damage will increase social unrest [69]. This theory states that social conflicts are influenced by environmental conditions [69].

In the indicator of eco-crisis, there are beliefs about attitudes to avoid environmental damage [35]. Some students lack information about the environmental issues that have arisen and do not understand the concept of environmental protection, which has been extensively utilized by humans. Environmental damage can be avoided by implementing the 4R + C (refuse, reduce, reuse, recycle, and composting) principles [70]. It has been demonstrated that 4R + C activities can prevent damage and environmental problems in Canada [71].

Furthermore, through the indicator of the balance of nature, there is a belief that the role of human behavior is balancing environmental sustainability. Some students understand environmental preservation and the causes of environmental damage [35]. In addition, students can provide examples of implementing environmental preservation to achieve sustainable development. The balance of environmental sustainability can be achieved through environmental education programs that foster logical intelligence and the ability to reason rationally in order to contribute to the balance of natural sustainability [57].

3.3. Student's Environmental Care Attitudes Based on Gender Differences

The study of environmental care attitudes can be viewed as an interesting approach if an analysis of gender differences in environmental care attitudes or gender equality is conducted. The following is the analysis of gender differences in high school students in the Pati Regency based on environmental care attitudes.

The results of the Mann-Whitney test indicated that there is a significant difference between men and women, as shown in Table 6. The indicator of anti-exemptionalism has an Asymp-Sig (2-tailed) value of 0.005 < 0.05, whereas the indicator of eco-crisis has a value of 0.000 < 0.05. Per the Mann-Whitney test, there is no significant difference between men and women regarding the remaining three indicators, namely limits to growth, anti-anthropocentrism, and balance of nature. The indicator of limits to growth has an Asymp-Sig (2-tailed) value of 0.015 < 0.05, the indicator of anti-anthropocentrism has an Asymp-Sig (2-tailed) value of 0.670 > 0.05, and the indicator of balance of nature has an Asymp-Sig (2-tailed) value of 0.692 > 0.05. Thus, it can be concluded that gender differences can affect environmental care attitudes as seen from the indicators of anti-exemptionalism and eco-crisis.

Table 6. Results of the Mann-Whitney Test of gender on environmental care attitudes.

Test Statistics [a]					
	Limits to Growth	**Anti Anthropocentrism**	**Balance of Nature**	**Anti Exemptionalism**	**Eco Crisis**
Mann-Whitney U	3051.500	3729.500	3737.500	2943.500	2672.000
Wilcoxon W	5607.500	6285.500	9732.500	5499.500	5228.000
Z	−2.437	−0.426	−0.396	−2.797	−3.561
Asymp. Sig. (2-tailed)	0.015	0.670	0.692	0.005	0.000

[a] Grouping Variable: Gender.

In the indicator of the balance of nature, male students have a slightly higher average score than female students. The indicator of the balance of nature demonstrates that individuals have the capacity to preserve the balance of nature [72]. According to the Multiple Intelligences theory, men have a more rational nature, allowing them to later contribute to restoring natural damage [73,74]. This study found that the average environmental care attitudes of female students differed from male students in terms of indicators of limits to growth, anti-anthropocentrism, anti-exemptionalism, and eco-crisis [35,36,75]. More details are provided in Figure 3.

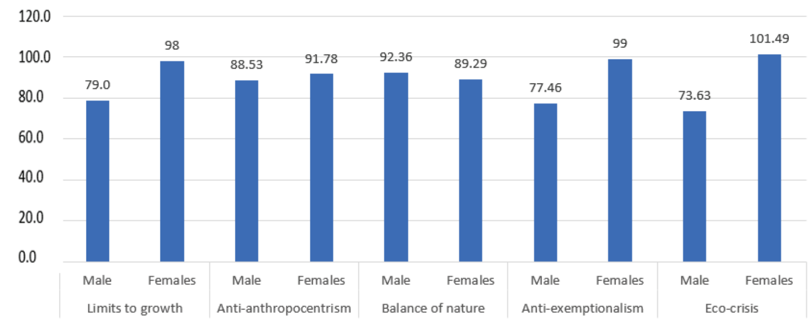

Figure 3. Analysis of the average score of environmental care attitudes based on gender.

Following Figure 3, research indicates that women in India are more likely to practice environmental protection than men [76]. It is supported by Sahin and Tekzoz's research that women are more engaged in pro-environmental activities and conservation behavior than men [77,78]. This is similar to research conducted by Tikka, Kuitunen, and Tynys that indicates women have a greater environmental responsibility than men [79]. Therefore, a program of environmental education involving male students is required to enhance environmental care attitudes.

Based on Figure 3, the limits to growth indicator, which has a value of 79.0 for males and 98 for females, proves that the graph shows a significant increase, but it is proven that, based on the Mann-Whitney test, the limits to growth indicator does not show that there is a significant difference. It differs from the anti-exemptionalism and eco-crisis indicators, which show a significant increase in the chart. In addition, the values obtained by the anti-exemptionalism, and eco-crisis indicators, have been proven in the Mann-Whitney test.

4. Discussion

Environmental problems are problems caused by environmental degradation and are affected by human attitudes and caring for the environment [34]. Environmental care is associated with the mutual connection between humans and environmental attitudes [80]. In order to maintain life and conduct daily activities, humans are closely attached to their environments [81,82]. The relationship between humans and the environment can become problematic when humans exploit the environment for their personal benefit and disregard the sustainability of nature. Therefore, environmental care must be taught to children from an early age to change attitudes toward environmental issues [83–85]. Environmental care attitudes are so essential that they must be taught in educational programs [86,87].

This study examined the implementation of the environmental curriculum in Adiwiyata schools, students' environmental care attitudes at Adiwiyata High School in the Pati Regency were based on the new ecological paradigm (NEP) scale, and gender differences in students' environmental care attitudes were based on the new ecological paradigm (NEP) scale. This study indicated that the main objective of Adiwiyata schools is to educate students about environmental care, with an emphasis on fostering environmental literacy so that each student develops environmental care attitudes. Using an environmental education curriculum with environmental care values, Adiwiyata schools have a strategic role in increasing environmental care attitudes [88]. The teacher plays an important role as a facilitator in developing student behavior patterns and forming environmental care attitudes by implementing an integrated environmental education curriculum in all subjects. This is similar to previous research demonstrating the significance of an environmental education curriculum for students' educational development [89,90]. This argument is supported by studies from various countries. Environmental care attitudes in Canada explain the importance of environmental education in enhancing environmental care attitudes among students [91]. It is different in India, which explains that environmental education is included in the curriculum and manifests itself in numerous student practices or exercises to protect the environment [92].

The Adiwiyata program carried out various activities, including the use of greenhouses and environmental activities based on participation, such as using mini-forests, tree planting, and the campaign to reduce plastic waste. The purpose of this activity is to promote environmental literacy and facilitate student learning. Students can become more environmentally aware through interaction with the environment [93]. According to research conducted in France, greenhouses can enhance students' environmental awareness [94]. This differs from research conducted in England, which indicates that the use of greenhouses can reduce gas emissions and stabilize school climate [95]. In addition, the Adiwiyata program includes environmental activities based on participation that emphasize teaching students to care for the environment. According to behaviorism theory, a routine and self-habituation that is repeated on a daily basis will be instilled and remembered by students, so that the routine that has been carried out will occur subconsciously and immediately [96,97]. Behaviorism is considered one of the most effective methods of education for achieving learning objectives, as students tend to think, conduct, and act following environmental norms [98,99].

Furthermore, the analysis of students' environmental care attitudes at Pati Regency high schools is included in the moderate category. The indicator of the balance of nature has the highest environmental care attitude index value when compared to the indicators of limits to growth, anti-anthropocentrism, anti-exemptionalism, and eco-crisis, as shown in Table 5. The indicator of the balance of nature described how human behavior can balance the environmental sustainability [35]. This study determined that some students no longer have the potential to cause environmental damage in the future. According to research by [100], students understand the concepts of reduce, reuse, and recycle and contribute to preventing environmental damage and restoring environmental balance.

In addition, an analysis of gender differences based on the new ecological paradigm (NEP) scale demonstrated that women are more concerned with environmental issues than males. This is similar to previous research on environmental care attitudes in China, which revealed that women scored higher [76]. Figure 3 indicates that women have the highest average scores for the indicators of limits to growth, anti-anthropocentrism, anti-exemptionalism, and eco-crisis.

The indicator of limit to growth showed that women have high knowledge of environmental care attitudes. Several studies, comparatively, indicate that males are more knowledgeable about environmental issues because they have greater access to higher education [101,102]. This is influenced by the development of social norms in society. In the past, parents believed that only boys could pursue higher education, but today, many parents believe that girls have the same right to pursue the highest level of education [103]; following the feminism theory that believes women have the same rights as males in education, the economy, and social life [104]. In addition, ecological feminism hypothesizes that because women are concerned with environmental issues, they can prevent environmental problems [105,106]. Therefore, women have a higher degree of knowledge than men. The roles held by women are empathic and emotional, whereas males are better at regulating their emotions [107]. The limit to growth indicator has an appeal because there is a finding that the average value obtained from the limit to growth indicator shows a high value.

However, based on the Mann-Whitney test shows that the limit to growth indicator has no significant difference between men with women.

The indicator of Anti-anthropocentrism described the role of women in natural resource utilization and environmental preservation. Sociological theory explains that gender differences are not only biological but also cultural and social [108]. In a society's social structure, women and males have distinct roles. In terms of the family, it is the responsibility of women to nurture children, provide affection, and teach environmental awareness to the next generation [79,109]. Men, however, prioritize the role of economic providers and market activities, which encourages them to be more skilled, rational, and competitive than women [110]. Therefore, men score lower than women on the anti-anthropocentrism indicator. The findings in this study have an interest or something unique in that the anti-anthropocentrism indicator has a high average value, but as seen from the Mann-Whitney test, the anti-anthropocentrism indicator shows no significant difference between men and women.

Then, the indicator of anti-exemptionalism indicated that women have a sense of responsibility to regulate and protect the environment. The findings on the exemptionalism indicator show that there is a significant difference based on the Mann-Whitney test. Based on previous research it was found that women have more pro-environmental behavior than men [111]. Theoretically, gender differences assume a connection between processes and social values. Therefore, women are better able to respect the needs of others and demonstrate altruism in everyday life than men. Altruism is a human attitude that seeks to enhance the well-being of others; however, this altruism appears to be closely linked to environmental management and environmental protection [44].

In addition, the indicator of eco-crisis demonstrated that women engage in practices that prevent or restore environmental damage and it is proven that women have significant differences compared to men based on the results of the Mann-Whitney test; following prior research indicating that women care about environmental preservation [42,112,113]. This is also in line with the socialization theory statement that women have a stronger and more sensitive "caring ethic" [114]. The research conducted by Dagher and Singh stated that the environmental care attitudes of female students were higher than those of male students [42,115]. Educational activities related to environmental management and utilization are needed for both male and female students. Educational activities consisting of the implementation of environmental education for both male and female students are one of the most effective methods for improving environmental care attitudes. The purpose of environmental education is to establish an awareness of environmental issues in students' attitudes [116]. Implementing environmental education in teaching and learning activities creates students with the responsibility to manage and preserve the environment and support sustainable development so that they can later actively participate in addressing environmental problems [117,118].

Furthermore, based on the results of the Mann-Whitney test that the anti-exemptionism indicator and the eco-crisis indicator have a significant gender difference between men and women towards environmental care attitudes. First, the anti-exemptionism indicator explains that women have more responsibility towards the environment than men. There are findings in the research that women have a sensitive character and have more feelings than men [119,120]. Based on these characters, it is evident that women own environmental awareness behavior. In addition, there are previous research findings that women can have a bond with nature [121].

Second, the eco-crisis indicator states that women are more pro-environmental in preventing environmental damage than men. This is supported by previous research findings that women participate in pro-environmental activities and adopt more sustainable lifestyles than men [78,122]. In line with this statement that research has been conducted in China, by applying sustainable style principles, women show less use of plastic bags and prefer to use reusable bags when shopping [123].

This study has significant implications for educators, future researchers, and knowledge related to environmental care attitudes. First, in relation to the environmental care attitude of students in the moderate category, where female students have a higher level of environmental care attitude than male students, it is necessary to play the role of implementing environmental education regularly or repeatedly, with the teacher's encouragement, to significantly influence the strengthening of students' environmental care attitudes. Based on this study's findings, environmental education activities need to be focused on men. The first activity is providing knowledge about the environment and introducing the use of natural resources with the principles of sustainable development, introducing the application of environmental management, and providing knowledge of the impact of environmental problems. The second activity directs men to carry out participatory-based environmental activities, such as introducing ways to conserve the environment, manage natural resources and carry out activities to prevent environmental damage by activating the role of 4R + C (refusal, reduce, reuse, recycle, and composting). Then, the implementation of environmental education in learning activities that are integrated into the curriculum is anticipated to strengthen students' environmental care, allowing them to identify, evaluate, and find solutions to environmental issues and problems. Therefore, to implement environmental education, it must collaborate with school principals, teachers, and students to change students' environmental care attitudes.

According to the results, this research showed that gender differences play an important role in environmental education and managing the environment. It can be confirmed that women have a high potential for student environmental care attitudes.

Second, teachers must take an active role in enhancing students' environmental awareness by implementing environment-based teaching materials and directing students to participate in organizations or activities related to the environment. Regularly organize environmental activities, such as competitions about the environment, designing models made from recycled materials, planting trees, and environmental quizzes.

Third, it is expected that this study will contribute to future research. Future researchers can test this study's hypotheses regarding the implementation of Adiwiyata schools, the environmental care attitudes of Adiwiyata school students, and the analysis of students' environmental care attitudes using the new ecological paradigm (NEP) scale in terms of gender differences using samples from their own countries.

Fourth, this research is believed to have contributed to knowledge related to environmental care attitudes. The formation of an attitude of caring for the environment can be started from an early age in the future younger generation. Environmental knowledge is needed to form good habits and will impact human attitudes that care and prevent environmental damage. The potential implication for policies and practices in the field is that humans will consciously prevent environmental problems through tree planting, reducing plastic waste, and not disposing of waste in rivers.

This study has limited research subjects because the research subjects were class XI students of the Adiwiyata program in the Pati Regency. Thus, it is necessary to carry out further research with the same scope.

5. Conclusions

The study results show that Adiwiyata schools have a curriculum integrated with environmental education and implemented in the learning process at school. The environmental education curriculum can influence students' environmental care attitudes. In addition, greenhouses and environmental activities based on participation are required to better students' environmental care attitudes. Students' environmental care attitudes at Pati Regency high schools still need to be enhanced, as the analysis showed that students' environmental care attitudes were in the moderate category with a score of 69.67%. Gender differences on the new ecological paradigm (NEP) scale have a significant impact on environmental care attitudes, and women have higher environmental care attitudes than men. Based on the indicators of limits to growth, anti-anthropocentrism, anti-exemptionalism, and eco-crisis, women have a high potential for student environmental care attitudes. This is because, according to the limits to development indicator, women are knowledgeable about human environmental exploitation. Indicators of anti-anthropocentrism suggest that women have pro-environmental attitudes and make effective use of natural resources. Then, based on the indicator of anti-exemptionalism, the individual has sensibilities and cares about the environment. Moreover, the indicator of eco-crisis demonstrates that women can prevent environmental damage; following the sociological theory that states women have better ethics based on the values of compassion and responsibility compared to men. This research implies that environmental education plays an important role in gender differences through the Adiwiyata School program, which has an environmental education curriculum and participatory-based environmental activities to increase students' environmental care attitudes. Environmental education implementation needs to focus on men through developing environmental knowledge and providing guidance on participatory-based environmental activities.

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Article

Students’ Perceptions towards the Role of Online Teaching Platforms in Enhancing Online Engagement and Academic Performance Levels in Palestinian Higher Education Institutions

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Abstract: The present research aimed to determine the role of online teaching platforms in enhancing learning and teaching as perceived by bachelor students of English specialization. This study also sought to examine the association between students’ engagement and their academic performance during online learning. In doing so, a quantitative approach was used to collect data, and 423 bachelor students from three Palestinian higher education institutions (Al Quds Open University, An Najah National University, and Arab American University) completed a closed-ended questionnaire. The study’s outcomes demonstrated that the students’ attitudes toward the role of online teaching platforms in enhancing their learning can be classified as positive and negative, and these attitudes varied among the respondents due to problems and challenges during online learning and previous experiences, skills, and learning style. Moreover, about 58.6% of students were dissatisfied with their online learning and had negative attitudes toward online teaching platforms. Therefore, more future studies relating to the design of online courses, resources that are available on the platform, and online teaching strategies that are considered fundamental components for fostering students’ engagement at higher education institutions should be taken into account. Moreover, further studies involving more universities with samples from different specializations will confirm or contrast the findings of the current study.

Keywords: online teaching platforms; online engagement; academic performance; students’ perceptions; e-learning; higher education institutions

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1. Introduction

E-learning, defined as an online learning paradigm that utilizes information technology, has become an increasingly popular method of education in recent years [1]. It enables students to engage in synchronous or asynchronous learning experiences, connect with instructors and classmates, and utilize various communication and information technology tools regardless of location. The incorporation of digital technology with instructional techniques has resulted in significant educational innovation, making e-learning a critical component of higher education curricula worldwide [2,3].

E-learning has not been acknowledged as a replacement for traditional learning methods [4]. Rather, it is viewed as a complementary approach that can leverage various learning theories to facilitate student learning. Behaviorism, for example, is one such learning theory that has been applied to online activities, enabling students to receive immediate feedback in the form of scores or other types of assessment [5]. Constructivism, on the other hand, emphasizes the importance of interaction between students, teachers, and content, allowing students to contextualize the material and learn through active engagement [6–8].

Student engagement is crucial for successful online learning experiences, and it is influenced by various factors, such as instructors’ incorporation of technology-based pedagogy and tasks that promote interaction [8,9]. Social stimuli, such as breakout rooms, discussion boards, forums, wikis, and resource-sharing systems, are important for stimulating student engagement [10]. The level of online engagement also depends on effective interaction between teachers and students, which can be challenging to achieve due to the diverse ways in which students interact with online courses [11,12].

Thus, e-learning has become a critical component of higher education curricula worldwide, providing students with a flexible and accessible learning experience. Incorporating various learning theories and promoting student engagement through effective interaction and technology-based pedagogy can enhance the online learning experience and contribute to successful learning outcomes.

Dwivedi et al. [8] have highlighted the importance of the teacher's role in online learning, which positively influences students' desire for learning. Effective online instructors encourage student engagement with timely, active, continuous support that promotes their personal connection [13,14]. The engagement and academic performance of students are significantly influenced by the online learning platform. Goh et al. [15] reported that using an e-learning platform resulted in better learning performance and satisfaction, while Tick [16] argued that students who use e-learning platforms in their learning are generally more engaged in the lesson, which significantly affects their academic achievement.

The challenge of maintaining academic success, achievement, and engagement at higher education institutions (HEIs) remains global. Therefore, studies that investigate the relationship between students' engagement and academic performance in online learning settings should be emphasized [17]. Thus, monitoring online student engagement can help instructors and students adapt their teaching and learning methods based on how motivated, engaged, and interested the students are [18].

Furthermore, Barba, Kennedy, and Ainley [19] stated that students who demonstrated higher levels of behavioral engagement were more likely to succeed and obtain better grades. Additionally, higher student participation can lead to more in-depth learning [12]. Students' performance also improves with increased interaction and participation in online discussion forums [20]. In the study of Goh et al. [15], university students' academic performance was influenced by their e-learning experiences.

According to Jumareng et al. [21], learning platforms strongly emphasized the transition from teacher-centered to learner-centered learning. Therefore, the instructor must know how to handle ICT tools effectively to use interactive strategies to improve engagement and communication in online education. Therefore, rather than simply presenting the material, online teaching and learning should aim to support the students' needs and expectations. Luan et al. [22] argued that an online learning platform can positively impact students' educational development and improve their capacity for independent learning. Studies also showed that the increased number of students using e-learning implies that their performance improved significantly through online learning platforms [23].

Qays et al. [24] have reported that online learning environments require improvement in terms of students' participation and experiences. In response, students are encouraged to utilize social media, digital tools, and programs to improve their learning opportunities. Holzweias et al. [25] suggested that students' positive impressions of online learning are related to activities that facilitate reflection and knowledge sharing with others.

In contemporary education, universities utilize technology and ICT tools to mitigate students' weaknesses and enhance their engagement. Altinay [26] argues that online collaborative learning can improve the quality of teaching in large classes. Therefore, educators must continue to explore strategies for promoting engagement and participation in university online courses, including online teaching and learning platforms. However, developing countries face difficulties in implementing e-learning systems due to digital gaps [27]. Even though there have been significant investments made in establishing e-learning systems at Palestinian universities for more than 15 years, Palestine's current political and economic issues are considered the key obstacles preventing the further growth of e-learning. In our research, Palestinian higher education institutions such as Al Quds

Open University, which is regarded as the leading university in introducing open education system initiatives in the Palestinian context since 2008; An Najah National University, which has been promoting online teaching and learning since 2012; and Arab American University, the largest private university in Palestine, have introduced e-learning since 2018, in which university teaching is continuously shifted into online teaching, whether completely or partially utilizing online platforms such as Moodle and Zoom. However, educators must be aware that education can become fully synchronized at any time due to unstable conditions. Hence, they should employ innovative strategies and methods to enhance students' online engagement.

Given the value of online teaching platforms in e-learning settings, the current study aims to identify students' attitudes toward online teaching platforms, evaluate the role of online teaching platforms in enhancing students' engagement levels, examine the association between students' online engagement and academic performance levels, and determine the correlation between students' perspectives toward their instructors' roles in their online learning and engagement. The research questions guiding the study are as follows:

1. What is the role of online teaching platforms in enhancing Palestinian university students' learning according to the students' perspectives?
2. To what extent do students' year(s) of study, university, and the type of online course influence their perspectives on the role of online teaching platforms in enhancing engagement and academic performance levels?
3. Is there a significant relationship between students' engagement and their academic performance levels?
4. Is there a significant relationship between students' attitudes toward online teaching platforms and their engagement?
5. Is there a significant relationship between students' perspectives toward their instructors' roles in online learning and their engagement?
6. Is there a significant relationship between students' perspectives toward their instructors' roles in online learning and their academic performance levels?

The following hypotheses were developed based on the research questions:

H1: *There are no statistically significant differences at $\alpha \leq 0.05$ in the role of online teaching platforms in enhancing students' learning from their point of view due to year(s) of study, university, and the kind of online course variables*.

H2: *There is a positive relationship at $\alpha \leq 0.05$ between students' engagement and their academic performance levels.*

H3: *There is a positive relationship at $\alpha \leq 0.05$ between students' attitudes toward online teaching platforms and their engagement.*

H4: *There is a positive relationship at $\alpha \leq 0.05$ between students' perspectives toward the instructor's role in online learning and their engagement.*

H5: *There is a positive relationship at $\alpha \leq 0.05$ between students' perspectives toward the instructor's role in online learning and their academic performance levels.*

2. Literature Review

In recent years, there has been an increasing interest in exploring students' experiences and perceptions of online learning, particularly in light of the COVID-19 pandemic. For example, Lei and Medwell [28] found that students appreciated the flexibility of Online Collaborative Learning (OCL), access to materials, and the ability to receive feedback from peers and teachers. However, some students also reported difficulties in developing initial contact with others, maintaining group participation, accessing the Internet, and dealing with economic background problems. Warren et al. [29] investigated the impact of blended learning on students' academic self-efficacy and found that it increased their satisfaction and improved their experiences. Farrell and Brunton [30] highlighted the importance of various psychosocial and structural factors, such as peer groups, stimulating online teachers, and self-belief, as well as an interactive online course structure and balancing life commitments, in promoting successful student engagement. Tarhini et al. [31] argued that positive student experiences in e-learning systems are crucial for student satisfaction, and Aparicio, Bacao, and Oliveira [32] emphasized that student satisfaction is a crucial determinant of the success of e-learning. Additionally, Sabbah and Yildiz [33] pointed out the importance of effective online course design in enhancing students' satisfaction, performance, knowledge, and skills, while Demuyakor [34] drew attention to the importance of incorporating modern pedagogies to improve student satisfaction. Gopal, Singh, and Aggarwal [35] found that the quality of the instructor, course design, and feedback significantly enhances students' satisfaction and performance in online classes, and Virtanen et al. [36] discovered that students' satisfaction is a crucial predictor of their academic experience in online learning.

In addition, it is worth mentioning that students' perceptions and attitudes are critical factors in the success of the transition to online education. Aderibigbe [37] found that students' engagement level through the online discussion forum was high, while Friska [38] came to the conclusion that most students have a positive attitude toward e-learning in general. However, Adnan and Anwar [39] confirmed that online learning might be ineffective in countries such as Pakistan, where most students struggle to access the Internet due to technical and economic problems.

Thus, to promote successful online learning and teaching experiences, higher education institutions need to shape students' perceptions and prepare them to learn through various types of online learning. Conversely, Coman et al. [40] found that Romanian university teachers and students were unprepared for the abrupt shift to entirely online learning and teaching, emphasizing the importance of proper preparation and training. In contrast, an empirical study conducted in the National Capital Territory of Delhi revealed that even though the students view e-learning as equivalent to face-to-face learning, the study demonstrated a similar experience of being educated through traditional teaching [41].

Research has shown that planning for meaningful interaction is essential for maintaining engagement in online learning. Ramaha and Karas [42] suggested the use of an interactive avatar for asynchronous e-learning systems that can detect students' motivation, maintain engagement, provide feedback, reward performance, provide different levels of difficult tasks, praise efforts, encourage persistence, and provide assistance. Understanding how students access, attend, and participate in online classes is also crucial for improving their academic success. In this vein, Nieuwoudt [43] found a significant positive relationship between final grades and the number of hours students spent on the Learning Management System (LMS). Similarly, Dumford and Miller [11] reported that the more online courses a student takes, the less collaborative learning the student engages in. The COVID-19 pandemic has also highlighted the influence of technology dependence and digital literacy on students' achievement. Essel et al. [44] conducted a descriptive correlational study that showed that students with low information and communication technology (ICT) experience experienced more significant technology-induced stress and techno-complexity. Another study based on transactional distance theory and Bloom's taxonomy theory showed significant support for the interdependent relationship between transactional distance and Bloom's taxonomy theories in using online learning platforms to improve students' academic achievement and satisfaction [45].

3. Materials and Methods

3.1. Participants

A sample of 423 students from three Palestinian universities (An Najah National University (ANNU), Arab American University (AAU), and Al Quds Open University (AQOU) responded to closed-ended questions using random sampling; to do so, researchers posted an online survey, an invitation letter outlining the study's goals and who was eligible to participate, and a consent form on the students' academic portal with support from the head of the English department. In addition, survey was distributed in person to students to reach the final group of 423 students. Demographic information about the participating students is presented in Figures 1–3.

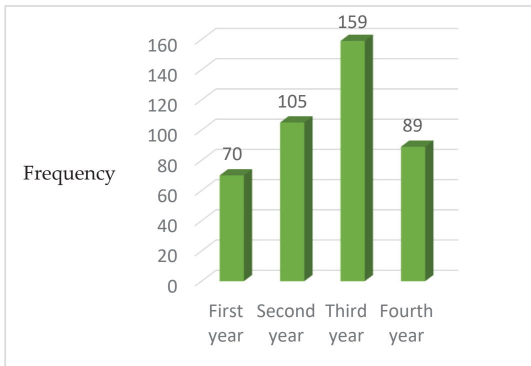

Figure 1. Sample distribution by year of study variable.

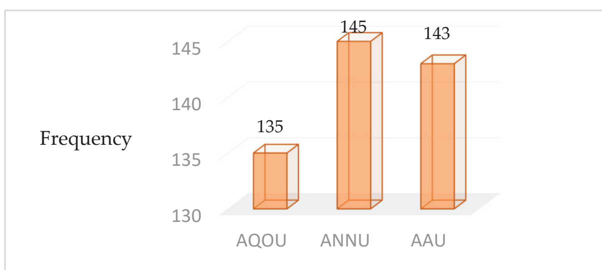

Figure 2. Sample distribution by university variable.

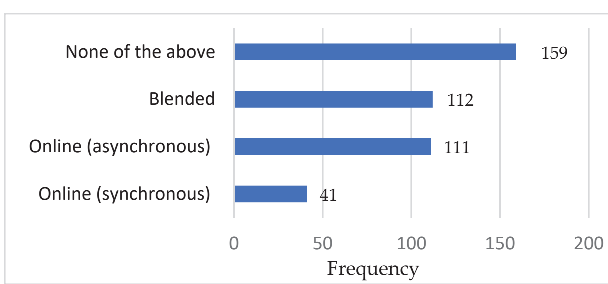

Figure 3. Sample distribution by kind of online course variable.

According to the figure, the third-year students had the highest frequency (159) and percentage (37.6%), followed by 105 students in second year (24.8%), 89 in fourth year (21%), and 70 in first year (16.5%).

According to Figure 2, 145 respondents—constituting the majority (37.6%)—are from ANNU, followed by 143 AAU students (33.8%) and 135 AQOU students (31.9%).

Figure 3 illustrates that majority of the participants (37.6%) did not have a specific online course, while 112 students had blended online courses (26.5%), 111 had asynchronous online courses (26.2%), and 41 had online synchronous (9.7%).

3.2. Instrument

The data were collected through a survey instrument designed and developed by the researchers, based on the research questions and the previous literature such as studies of Dumford and Miller [11], Friska [38], Adnan and Anwar [39], Coman et al. [40], Essel et al. [44], Sørum [46], Cranfield et al. [47], Hussein et al. [48], Yasin et al. [49], Borg et al. [50], and Abou-Khalil et al. [51]. The survey was distributed to the participants during the second and summer semesters of the academic year 2021–2022.

3.3. Research Validity and Reliability

In order to ensure the validity of the survey instruments, two experts in the field of language and literature didactics from Granada University in Spain were consulted to review the accuracy of the questions. Following the feedback provided by the experts and the necessary revisions by the researchers, the questionnaire was finalized. Moreover, the reliability of the questionnaire was assessed by calculating the Cronbach alpha coefficient; the reliability of each domain and the whole questionnaire was 0.795, 0.856, 0.771, 0.732, and 0.847, respectively, which is an acceptable reliability index. Obviously, reliability values range between 0.73 and 0.84, indicating that the tools are reliable and that researchers can draw meaningful conclusions from the data and analysis.

3.4. Procedures

The study was conducted in several stages. Firstly, the researchers developed a data collection tool in English language based on the research questions and related studies, which consisted of five dimensions covering students' background information, attitudes towards online teaching platforms, the roles of online teaching platforms in enhancing engagement levels, online platforms, and academic performance levels, and their perspectives towards the role of the instructor in online learning. Secondly, the developed survey was sent to two experts in educational sciences from Granada University (Spain) to validate the accuracy of the questions and survey items. Thirdly, the researchers obtained permission from ANNU, AAU, and AQOU to facilitate the researcher's task and collect data from bachelor students of English specializations, and obtained participants' agreement to participate in the study via a consent form that addressed ethical issues such as voluntary participation, data security, and anonymity. Fourthly, the online survey form was submitted to each university's portal and webpage, accompanied by an invitation letter that explained the research's main objective. In addition, the survey was distributed in person to students, resulting in a final sample of 423 participants from ANNU, AAU, and AQOU. Finally, the researchers used IBM SPSS Statics version 25 to record and analyze quantitative data. To analyze the data, the researchers used various statistical treatments, including computational averages, means, standard deviations, and percentages of responses of study sample individuals to the questionnaire as a whole and to each of its paragraphs; an independent T-test; a one-way ANOVA; and the Sheffee Test. Additionally, the researchers calculated the alpha-Cronbach coefficient to assess the reliability of the study's instruments and used the Pearson Correlation Test to examine the relationship between the dimensions.

3.5. Data Analysis

The researchers reviewed the data of survey before entering it into the computer for data analysis. The impact degree ranged between "very high" and "very low" using a 5-point Likert scale, with percentages of 80% and more, 70–79.9%, 60–69.9%, 50–59.9%, and 50% and less, respectively. In addition, all the students' responses were between "strongly disagree" and "strongly agree," and the researchers represented the results into scores 1, 2, 3, 4, and 5, accordingly.

4. Results

4.1. Results Related to the First Question

To answer the first question, the researchers measured mean and SD differences between repeated measures with the same instrument for each dimension and the total degree, as shown in Tables 1–4 below.

Table 1. Mean and Standard Deviation of the respondents' answers (dimension one).

No.	Items	Mean	Std. Deviation	Response Rate	Impact Degree
1	In an online course, I spend more time doing tasks than in an in-person course.	3.2435	1.23334	64.8	Medium
2	When I'm taking an online course, I spend a lot of time fixing technical problems.	3.3712	1.21281	67.4	Medium
3	The design of online learning activities encourages me to interact actively.	2.9220	1.13583	58.4	Low
4	During online classes, I find it difficult to express my ideas, comments, and answers.	3.0473	1.26852	60.8	Medium
5	Asynchronous classes (e.g., Moodle) are easier than synchronous classes (e.g., Zoom).	2.9551	1.09949	59	Low
6	Overload information of online course make learning more difficult.	3.3002	1.13002	66	Medium
7	I am satisfied with the online lectures I am taking.	2.7849	1.16365	55.6	Low
	Total degree	3.0892	0.54780	61.8	Medium

Table 2. Mean and standard deviation of the respondents' answers (dimension two).

No.	Items	Mean	Std. Deviation	Response Rate	Impact Degree
8	Reading everyone's responses kept me interested and helped me learn more.	3.2317	1.13047	64.6	Medium
9	The online platform increases the number of opportunities to engage in meaningful conversation with professors and other students.	3.1608	1.13858	63.2	Medium
10	Online platforms help me to interact with online course content in more than one format (e.g., text, video, audio, interactive games, or simulations).	3.3522	1.10633	67	Medium
11	I actively participate in and perform in online lectures because the materials are well organized, ranging from simple to complex, and from knowing to practicing"	2.9787	1.10878	59.4	Low
12	The wide range of online learning activities allows me to choose activities that are suitable for my level of English.	3.1277	1.15515	62.4	Medium
13	Breakout groups, discussion boards, discussion forums, wikis, and resource sharing foster my interaction with other students and help me comprehend content easily.	3.1820	1.12383	63.6	Medium
14	I share information and resources with other students and instructors easily.	3.3428	1.18571	66.8	Medium
15	Online platform encourages positive cooperation among students and instructors.	3.2246	1.12455	64.4	Medium
16	An online teaching platform encourages active learning and strengthens connections between students.	3.0426	1.19560	60.8	Medium

Table 2. *Cont.*

No.	Items	Mean	Std. Deviation	Response Rate	Impact Degree
17	Online platforms offer a variety of resources that aid in the development of my knowledge and comprehension in online courses.	3.1773	1.14753	63.4	Medium
18	My online teaching platform increases my interest for taking English classes.	3.0189	1.14562	60.2	Medium
	Total degree	3.1672	0.73094	63.2	Medium

Table 3. Mean and standard deviation of the respondents' answers (dimension three).

No.	Items	Mean	Std. Deviation	Response Rate	Impact Degree
19	Learning through an online platform increased my achievement level.	3.0284	1.21568	60.4	Medium
20	I have limited skill and knowledge in using online platforms, which affects my achievement on online exams.	3.0993	1.21389	61.8	Medium
21	The materials on the online platform help me in improving my online course achievement.	3.0567	1.13814	61	Medium
22	I don't have enough time to complete exams and submit assignments on time which results in a low achievement.	2.8534	1.31606	57	Low
23	Poor connectivity affects my achievement negatively in some online courses.	2.5248	1.16575	50.4	Low
24	Large assignments and information overload in online courses lead to poor performance	2.6478	1.21456	52.8	Low
25	My ability to learn independently has improved.	2.8298	1.27103	56.6	Low
26	My grades are improving because of the online platform.	3.4326	1.18024	68.6	Medium
	Total degree	2.9341	0.60744	58.6	Low

Table 4. Mean and Standard deviation of the respondents' answers (dimension four).

No.	Items	Mean	Std. Deviation	Response Rate	Impact Degree
27	My professor doesn't have enough resources and skills for online teaching.	3.3168	1.08146	66.2	Medium
28	My professor delivered online learning materials in a different way.	3.1584	1.16056	63.2	Medium
29	My professor gives me enough time to engage in and understand the online course material.	3.1537	1.14060	63	Medium
30	My professor provides regular feedback.	3.2151	1.16974	64.2	Medium
31	Our professors teach us how to use the online platform correctly and provide us advice	3.2080	1.04370	64	Medium
32	Online learning materials are sufficiently explained by professors.	3.2695	1.10071	65.4	Medium
	Total degree	3.2203	0.66292	64.4	Medium

Table 1 presents the findings related to the first dimension of the survey, which explored students' attitudes toward online teaching platforms. The results indicate that students had a medium average response to items 1, 2, 4, and 6, as well as to the total degree, with an average ranging from 60.8% to 67.4%. In contrast, the average response to items 3, 5, and 7 was low, ranging from 55.6% to 59%. Based on these findings, it can be concluded that students' varied attitudes towards online teaching platforms are due to the problems they encountered during online lectures and their dissatisfaction with this new method of learning. Specifically, item 2 received the highest percentage of agreement, whereas item 7 received the lowest percentage.

In Table 2, the average response is presented as moderate for all items except for item 11, which shows a low level of agreement. The moderate average response ranges from 59.4% to 67.0%. These findings indicate that the students generally had a moderate level of agreement with the role of online teaching platforms in enhancing their online engagement levels. Conversely, item 11 had a low response rate of 59.4%. Based on the results of the second dimension, item 10 received the highest response, while item 11 had the lowest response.

Based on Table 3, it can be observed that the students' average response to items 19, 20, 21, and 26 falls within the medium range, varying from 60.4% to 68.6%. These findings suggest that students generally agree moderately that an online teaching platform can help them enhance their academic performance. Conversely, items 22, 23, 24, and 25 received low average responses ranging from 50.4% to 57.0%, indicating that the students have a low level of agreement on the effectiveness of the online teaching platform in enhancing their academic performance. Furthermore, the total degree of the role of the online teaching platform in enhancing students' academic performance is also at a low level, indicating that students have negative attitudes toward the ability of the online teaching platform to improve their academic performance. The item with the highest percentage is item 26, whereas the lowest percentage was scored by item 23.

Table 4 presents the findings of the fourth dimension, which indicates that all items had a medium average response ranging from 63% to 66.2%. These results imply that the students expressed moderate agreement with the professors' role in online learning in terms of their employment of online resources, skills, strategies, feedback, explanation, and guidance during online teaching. Item 27 had the highest percentage, which means that students had the highest level of agreement. Conversely, item 29 had the lowest percentage, indicating that students had the lowest level of agreement.

4.2. Results Related to the Second Question

To address the second research question, the researchers conducted Means and one-way ANOVA analyses, as presented in Tables 5 and 6.

Table 5 displays the mean and standard deviation differences of the survey's various domains, segmented by students' year of study. Notably, the second domain had the highest mean value of 3.3187 for fourth-year students, indicating their positive attitude towards the role of online teaching platforms in enhancing engagement levels. Conversely, the third domain had the lowest mean value of 2.7857, which favored first-year students in their perception of the role of online teaching platforms in enhancing academic performance levels. In the first domain, the second-year students had the highest mean value of 3.1320, while the first-year students had the lowest mean value of 3.0571. Similarly, the second domain had the highest mean value of 3.3187 for fourth-year students and the lowest mean value of 3.0506 for first-year students. Likewise, the third domain had the highest mean value of 3.0955 for fourth-year students and the lowest mean value of 2.7857 for first-year students. In the fourth domain, the highest mean value was 3.3092 for third-year students, while the lowest mean value was 3.1190 for first-year students. Overall, the results indicate that fourth-year students had positive perceptions towards online teaching platforms, as evidenced by the highest mean value of 3.1531 across all domains. Conversely, the lowest mean value of 3.0031 was observed among first-year students, suggesting their negative perceptions.

Table 5. Means and standard deviation according to the study year variable.

Dimensions	Year of the Study	N	Mean	Std. Deviation
Dimension 1	First year	70	3.0571	0.50925
	Second year	105	3.1320	0.51989
	Third year	159	3.0863	0.57706
	Fourth year	89	3.0690	0.56124
	Total	423	3.0892	0.54780
Dimension 2	First year	70	3.0506	0.80119
	Second year	105	3.1489	0.61891
	Third year	159	3.1458	0.74448
	Fourth year	89	3.3187	0.75876
	Total	423	3.1672	0.73094
Dimension 3	First year	70	2.7857	0.52954
	Second year	105	2.8440	0.59236
	Third year	159	2.9686	0.61783
	Fourth year	89	3.0955	0.62756
	Total	423	2.9341	0.60744
Dimension 4	First year	70	3.1190	0.61787
	Second year	105	3.2302	0.62889
	Third year	159	3.3092	0.70358
	Fourth year	89	3.1292	0.64879
	Total	423	3.2203	0.66292
Total	First year	70	3.0031	0.47989
	Second year	105	3.0888	0.41801
	Third year	159	3.1275	0.48584
	Fourth year	89	3.1531	0.46500
	Total	423	3.1027	0.46545

Table 6. Results of the one-way ANOVA test.

Dimensions		Sum of Squares	DF	Mean Square	F	Sig. *
Dimension 1	Between Groups	0.302	3	0.101	0.333	0.801
	Within Groups	126.336	419	0.302		
	Total	126.637	422			
Dimension 2	Between Groups	3.101	3	1.034	1.948	0.121
	Within Groups	222.362	419	0.531		
	Total	225.463	422			
Dimension 3	Between Groups	4.900	3	1.633	4.538	0.004 *
	Within Groups	150.810	419	0.360		
	Total	155.710	422			
Dimension 4	Between Groups	2.724	3	0.908	2.082	0.102
	Within Groups	182.729	419	0.436		
	Total	185.452	422			
Total	Between Groups	1.038	3	0.346	1.604	0.188
	Within Groups	90.385	419	0.216		
	Total	91.423	422			

* Statistically significant at level $\alpha \leq 0.05$.

Table 6 depicts the results of the statistical analysis, indicating that the hypothesis was not supported for the third dimension. Specifically, the findings reveal that there were statistically significant differences ($\alpha \leq 0.05$) in the students' perceptions toward the role of online teaching platforms in enhancing their learning across different years of study on the third dimension. However, no significant differences were observed across other dimensions. To further investigate these findings, the researchers conducted the Scheffe test to compare the different levels and identify where the differences occurred. The results proved that there were significant differences between the first and fourth years of study in the third dimension, with fourth-year students reporting higher positive perceptions towards the role of online teaching platforms in enhancing their learning, with mean difference score of −0.30979 *. However, there were no significant differences found in the other dimensions.

To examine the influence of the university variable, the researchers utilized Means and one-way ANOVA. Tables 7–9 present the results of these analyses.

Table 7. Means and standard deviation according to the university variable.

Dimensions	University	N	Mean	Std. Deviation
Dimension 1	Al Quds Open University	135	3.1545	0.52418
	An Najah National University	145	3.1399	0.53252
	Arab American University	143	2.9760	0.57042
	Total	423	3.0892	0.54780
Dimension 2	Al Quds Open University	135	3.4209	0.59930
	An Najah National University	145	3.1643	0.70859
	Arab American University	143	2.9307	0.78877
	Total	423	3.1672	0.73094
Dimension 3	Al Quds Open University	135	3.0398	0.55202
	An Najah National University	145	2.8733	0.65567
	Arab American University	143	2.8960	0.59764
	Total	423	2.9341	0.60744
Dimension 4	Al Quds Open University	135	3.4086	0.63046
	An Najah National University	145	3.1943	0.64401
	Arab American University	143	3.0688	0.67290
	Total	423	3.2203	0.66292
Total	Al Quds Open University	135	3.2560	0.41619
	An Najah National University	145	3.0929	0.44242
	Arab American University	143	2.9679	0.49107
	Total	423	3.1027	0.46545

Table 8. Results of one-way ANOVA test for dimensions 1–4.

Dimensions		Sum of Squares	DF	Mean Square	F	Sig. *
Dimension 1	Between Groups	2.780	2	1.390	4.713	0.009 *
	Within Groups	123.857	420	0.295		
	Total	126.637	422			
Dimension 2	Between Groups	16.687	2	8.343	16.784	0.000 *
	Within Groups	208.777	420	0.497		
	Total	225.463	422			
Dimension 3	Between Groups	2.253	2	1.126	3.083	0.047 *
	Within Groups	153.457	420	0.365		
	Total	155.710	422			
Dimension 4	Between Groups	8.171	2	4.085	9.679	0.000 *
	Within Groups	177.281	420	0.422		
	Total	185.452	422			
Total	Between Groups	5.784	2	2.892	14.184	0.000 *
	Within Groups	85.639	420	0.204		
	Total	91.423	422			

* Statistically significant at level $\alpha \leq 0.05$.

Table 9. Results of Scheffe's post hoc test between levels according to university variable.

Dependent Variable	University	University	Mean Difference
Dimension 1	Al Quds Open University	Arab American University	0.17847 *
	An Najah National University	Arab American University	0.16388 *
Dimension 2	Al Quds Open University	Arab American University	0.49017 *
	An Najah National University	Arab American University	0.23356 *
Dimension 3	Al Quds Open University	Arab American University	0.50785 *
	An Najah National University	Arab American University	0.14384 *
Dimension 4	Al Quds Open University	An Najah National University Arab American University	0.21439 * 0.33988 *
Total	Al Quds Open University	An Najah National University Arab American University	0.16303 * 0.28809 *

* Statistically significant at level $\alpha \leq 0.05$.

Table 7 presents the mean and standard deviation (SD) differences across all domains with respect to the university variable. Notably, the second domain obtained the highest mean score of 3.4209, indicating that AQOU students have the highest average agreement toward the role of online teaching platforms in enhancing their engagement. Conversely, the lowest mean score of 2.8733 was found in the third domain, indicating that ANNU students have the lowest average agreement toward the role of online teaching platforms in enhancing their academic performance levels. For the first domain, the highest mean score was 3.1545 in favor of AQOU, while the lowest mean score was 2.9760 in favor of AAU. Similarly, in the second domain, AQOU students had the highest mean score of 3.4209, while AAU students had the lowest mean score of 2.9307. The third domain showed that AQOU students expressed the highest mean score of 3.0398, while ANNU students expressed the lowest mean score of 2.8733. Regarding the fourth domain, the highest mean score of 3.4086 was in favor of AQOU, while the lowest mean score of 3.0688 was in favor of AAU. Overall, AQOU students had the highest average score of 3.2560, while AAU students had the lowest average score of 2.9679.

Table 8 illustrates the mean values and statistical significance of all domains and the total degree. The findings indicate that the statistical significance levels are below 0.05, indicating that there are statistically significant differences in the first, second, third, and fourth dimensions as well as in the total degree. Thus, the hypothesis's validity is rejected. Therefore, there are statistically significant differences at $\alpha \leq 0.05$ in the students' perceptions regarding the role of online teaching platforms in enhancing their learning as influenced by university variables in those dimensions. To examine the hypothesis, the researchers employed the Scheffe test (Table 9) to compare dimensions between levels to identify which levels exhibited differences.

Table 9 displays the mean differences across levels. The findings reveal significant differences in the first, second, third, fourth, and total degree dimensions, favoring AQOU students with higher-level perceptions of online teaching platforms' role in enhancing their learning compared to ANNU and AAU students. Moreover, the results indicate significant differences between ANNU and AAU, with ANNU students demonstrating higher-level perceptions of the role of online teaching platforms in enhancing their learning than AAU students. However, other comparisons are not statistically significant.

Tables 10–12 present the differences in the total degree of the tool, where the researchers employed Means and one-way ANOVA to examine the online course variable.

Table 10. Means and standard deviation according to the kind of online course variable.

Dimensions	Kind of Online Course	N	Mean	Std.
Dimension 1	Online (synchronous [live]—such as Google meeting or zoom)	41	2.9930	0.67609
	Online (asynchronous—such as Moodle)	111	3.0837	0.56242
	Blended (in-person and online [any form of online]; synchronous and asynchronous)	112	3.1071	0.53159
	None of the above	159	3.1051	0.51394
	Total	423	3.0892	0.54780
Dimension 2	Online (synchronous [live]—such as Google meeting or zoom)	41	3.1220	0.88715
	Online (asynchronous—such as Moodle)	111	3.0295	0.79661
	Blended (in-person and online [any form of online]; synchronous and asynchronous)	112	3.3019	0.64712
	None of the above	159	3.1801	0.68180
	Total	423	3.1672	0.73094
Dimension 3	Online (synchronous [live]—such as Google meeting or zoom)	41	3.1067	0.56566
	Online (asynchronous—such as Moodle)	111	2.8356	0.57406
	Blended (in-person and online [any form of online]; synchronous and asynchronous)	112	3.0592	0.58461
	None of the above	159	2.8703	0.63658
	Total	423	2.9341	0.60744
Dimension 4	Online (synchronous [live]—such as Google meeting or zoom)	41	3.1057	0.61999
	Online (asynchronous—such as Moodle)	111	3.0240	0.70812
	Blended (in-person and online [any form of online]; synchronous and asynchronous)	112	3.4048	0.67477
	None of the above	159	3.2568	0.59290
	Total	423	3.2203	0.66292
Total	Online (synchronous [live]—such as Google meeting or zoom)	41	3.0818	0.54431
	Online (asynchronous—such as Moodle)	111	2.9932	0.50174
	Blended (in-person and online [any form of online]; synchronous and asynchronous)	112	3.2183	0.43059
	None of the above	159	3.1031	0.42439
	Total	423	3.1027	0.46545

Table 11. Mean differences between the levels of the online course variable.

Dimensions		Sum of Squares	DF	Mean Square	F	Sig. *
Dimension 1	Between Groups	0.459	3	0.153	0.508	0.677
	Within Groups	126.178	419	0.301		
	Total	126.637	422			
Dimension 2	Between Groups	4.249	3	1.416	2.683	0.046 *
	Within Groups	221.214	419	0.528		
	Total	225.463	422			
Dimension 3	Between Groups	4.698	3	1.566	4.345	0.005 *
	Within Groups	151.012	419	0.360		
	Total	155.710	422			
Dimension 4	Between Groups	8.838	3	2.946	6.989	0.000 *
	Within Groups	176.614	419	0.422		
	Total	185.452	422			
Total	Between Groups	2.845	3	0.948	4.485	0.004 *
	Within Groups	88.579	419	0.211		
	Total	91.423	422			

* Statistically significant at level $\alpha \leq 0.05$.

Table 12. Scheffe's Post Hoc Test between levels according to kind of online course variable.

Dimensions	Kind of Online Course	Kind of Online Course	Mean Difference
Dimension 2	Online (asynchronous—such as Moodle)	Blended (in-person and online (any form of online); synchronous and asynchronous)	−0.27246 *
Dimension 3	Online (asynchronous—such as Moodle)	Online (synchronous (live)—such as Google Meeting or Zoom)	0.27112 *
Dimension 4	Online (asynchronous—such as Moodle)	Blended (in-person and online (any form of online); synchronous and asynchronous)	−0.38074 *
Total	Online (asynchronous—such as Moodle)	Blended (in-person and online (any form of online; synchronous and asynchronous)	−0.22506 *

* Statistically significant at level $\alpha \leq 0.05$.

Table 10 displays the mean and standard deviation (SD) for the kind of online course variable, and based on the mean scores for all kinds of online courses, the researchers included for comparison only the kind of online course that has the highest and the lowest mean average and excluded other mean scores. However, across all domains, blended courses received the highest mean score of 3.3019, while online courses (asynchronous, such as Moodle) received the lowest mean score of 2.8356. This suggests that students who took blended courses exhibited higher levels of agreement with the role of online teaching platforms in enhancing their engagement, while students who took online courses displayed the lowest level of agreement. In the first domain, blended courses received the highest mean value of 3.1071, while online synchronous courses (live), such as Google Meeting or Zoom, received the lowest mean value of 2.9930. Students who took blended courses had positive attitudes toward online teaching platforms, whereas those who took online synchronous courses had negative attitudes. In the second domain, blended courses received the highest mean score of 3.3019, while online asynchronous courses (such as Moodle) received the lowest mean score of 3.0295. Students who took blended courses displayed a high level of attitude toward the role of online teaching platforms in enhancing their engagement, while those who took online asynchronous courses showed a low level of attitude. For the third domain, online synchronous courses (live) (such as Google Meeting or Zoom) received the highest mean score of 3.1067, while online asynchronous courses (such as Moodle) received the lowest mean score of 2.8356. This indicates that students who took online synchronous courses expressed a higher average level of attitude toward the role of online teaching platforms in enhancing their academic performance than those who took online asynchronous courses. In the fourth domain, blended courses received the highest mean score of 3.4048, while online asynchronous courses (such as Moodle) received the lowest mean score of 3.0240. Students who took blended courses displayed a high-average level of perspective toward the instructors' role in online learning, while those who took online asynchronous courses displayed a low-average level of perspective. Overall, students who took blended courses had the highest average score of 3.2183, while those who took online asynchronous courses had the lowest average score of 2.9932 across all domains.

Table 11 shows the mean differences between the levels of the online course variable. The results reveal that significant differences were observed in the second, third, and fourth dimensions, as well as in the total degree. Consequently, the hypothesis was rejected. The findings suggest that, at a significance level of $\alpha \leq 0.05$, there are statistically significant disparities in the students' perceptions of the role of online teaching platforms in enhancing their learning based on the type of online course variable on those dimensions.

To further examine the differences between the levels and identify which levels showed variations, the researchers utilized the Scheffe test for dimensional comparisons (Table 12).

Table 12 presents the findings of a study that sought to identify differences in student perceptions between blended and online (asynchronous, specifically using Moodle) learning environments. The results show that the differences between the two types of learning environments were significant in the second and fourth dimensions, as well as the total degree, with blended learning receiving higher scores. Specifically, students who participated in blended courses expressed more positive perceptions of the role of online platforms in enhancing their learning. However, in the third dimension, students who used online (asynchronous, using Moodle) platforms had higher perceptions of the role of online teaching platforms in enhancing their learning compared to those who used online (synchronous, using platforms such as Google Meet or Zoom). The study did not find any statistically significant differences between the other comparisons.

4.3. Results Related to the Third Question

In order to address the third research question, the researchers utilized the Pearson Correlation Test to examine the relationship between students' engagement and their academic performance levels, as depicted in Table 13.

Table 13. Results of the Pearson Correlation Test.

Dimensions	Mean	Std. Pearson Correlation Value
Students' Performance Levels	2.9341	0.60744 * 0.456 *
Students' Engagement	3.1672	0.73094 *

* Significance Value = 0.000.

Table 13 shows that there is a moderate positive correlation between the students' engagement and their academic performance levels since the value of the coefficient of the Pearson Correlation Test was 0.456 and lies between +0.30 and +0.49, and the statistical significance value was 0.000. Hence, there is a significant relationship $\alpha \leq 0.05$ between students' engagement and their academic performance levels.

4.4. Results Related to Question Four

To answer the fourth research question, the researchers used the Pearson Correlation Test to find out the correlation between the students' attitudes toward online teaching platforms and their engagement, as shown in Table 14 below.

Table 14. Results of the Pearson Correlation Test.

Dimensions	Mean	Std. Pearson Correlation Value
Students' Attitudes toward online Teaching platform	3.0892	0.54780 * 0.400 *
Students' Engagement	3.1672	0.73094 *

* Significance Value = 0.000.

Table 14 shows that there is a moderately positive relationship at the level of significance $\alpha \leq 0.05$ between the students' attitudes toward learning through an online teaching platform and their attitudes toward the role of an online teaching platform in enhancing their engagement level since the coefficient value of the Pearson Correlation Test (r) was 0.400, and the value of (r) lies between 0.3 and 0.5.

4.5. Results Related to Question Five

To answer the fifth research question, the researchers used the Pearson Correlation Test to find out the correlation between the students' perspectives toward the instructor's role in online learning and their engagement level. The results revealed that there was a strong positive correlation at the level of significance $\alpha \leq 0.05$ in favor of students' perspectives toward instructors' roles in online teaching. The coefficient value of the Pearson Correlation Test (r) was 0.625, which is greater than 0.5.

4.6. Results Related to Question Six

To answer the sixth research question, the researchers used the Pearson Correlation Test to find out the correlation between the students' perspectives toward the instructor's role in online learning and their academic performance levels. The results showed that there was a weak correlation at the level of significance $\alpha \leq 0.05$ in favor of students' perspectives toward their instructors' role in online teaching. The Pearson correlation coefficient (r) value was 0.354 and lies between 0 and 0.3.

5. Discussion and Conclusions

The most relevant results have allowed the researchers to achieve the objectives set at the beginning of this research. These are, on the one hand, to identify students' attitudes toward online teaching platforms, and on the other hand, to assess the role of online teaching platforms in enhancing students' engagement level, examine the association between students' online engagement and their academic performance levels, and to determine the correlation between students' perspectives toward their instructors' role in their online learning and engagement.

The researchers have started assuming that the varied attitudes of students are influenced by their specific knowledge and skills that allow them to integrate that knowledge and experience with new skills into their online courses. The researchers also attributed a large number of respondents' dissatisfaction with online education to poor organization and design of online learning activities, difficulties in maintaining interaction and comprehending online materials when using the Moodle platform, infrastructure issues, professors' insufficient skills in online teaching, a lack of regular feedback about their progress from their instructors, and a limited number of resources that a student could access. These results coincide with those found in several studies [37,39,40,46–49]. On the other hand, the research conducted by Khan et al. [41] emphasizes the positive influence of the design of online courses on students' satisfaction, performance, knowledge, and skills. Besides, Gopal et al. [35] and Yasin et al. [49] agreed that in order to improve the effectiveness of online teaching, instructors should prioritize self-efficacy when designing online courses. The participants' low attitudes toward their asynchronous classes were consistent with the findings of previous studies, such as the research conducted by Borg [50], who found that students reported higher levels of comfort using online synchronous classes than both in-person and online asynchronous classes.

In addition, the researchers emphasized that online teaching platforms can help students to interact moderately with online courses in different forms because they offer a variety of resources such as breakout rooms, discussion boards, discussion forums, and wikis that aid in the development of their knowledge and comprehension in online courses. This is consistent with the findings of Aderibigbe [37] and Abou-Khalil et al. [51], who found that students expressed positive perceptions toward the platform's engagement tools and resources and felt engaged in the courses through online discussions. Sørum [46] also confirmed that students' motivation scored a higher percentage than autonomy and digital pedagogy in their ability to adapt to online learning. In contrast, Chen et al. [52] have stated that the Zoom platform needs to improve its communication and interaction, teaching functionalities, and student status management. In the same vein, Dumford and Miller [11] found a significant link between student engagement and the number of online courses taken. Farrell and Brunton [30] concluded that a successful online student engagement experience is influenced by various psychosocial and structural factors.

Furthermore, the researchers have begun to believe that there is a need to develop more materials for online learning, as well as specialized training courses and workshops to assist students in improving their online learning skills, experiences, and academic performance.

There appears to be broad agreement on the importance of student satisfaction in predicting academic experience in online learning [34–36,41,49,53–55].

The researchers assume that the instructors have the necessary skills, experiences, and resources to teach online courses, which is consistent with Almusharraf and Khanro [53], who found that the majority of students were satisfied with their instructors' support in terms of course activities, assessment, teaching pedagogies, and delivery of online lectures. On the other hand, Rajabalee and Santally [56] reported that students were dissatisfied with their instructors' role in online teaching.

The results also proved that students who took a higher percentage of online courses engaged less in collaborative learning. Moreover, students enrolled in AQOU demonstrated the highest level of agreement regarding the positive role of online teaching platforms in enhancing their engagement. This finding is consistent with the studies conducted by Borup et al. [57] and Conijn, Van den Beemt, and Cuijpers [58], who reported a positive relationship between MOOC activities and final grades in on-campus courses. Conversely, students at AAU showed the lowest level of agreement across all dimensions regarding the positive role of online teaching platforms in enhancing their learning, which could be attributed to their lack of experience with online learning compared to students at AQOU, which is an open university employing distance learning for all university degrees. This finding is supported by Nieuwoudt [43], who found a significant relationship between final grades and the number of hours spent by students on the Learning Management System (LMS). Similarly, Borg et al. [50] reported that in-person teaching was perceived as more effective than both synchronous and asynchronous online teaching. However, Friska [38] found that most students held a positive perception of e-learning in general, whether delivered synchronously or asynchronously and viewed it as a helpful aid to their learning process.

Additionally, students who took synchronous online courses expressed a higher level of agreement regarding the positive role of online teaching platforms in enhancing their academic performance than those who took solely asynchronous online courses. This finding is supported by Rinekso and Muslim [59], who found that the synchronous online discussion method of teaching was effective and should be used in teaching English synchronous courses. The results also stressed that the lack of skills, experience, and necessary requirements among students may have affected their attitudes toward the positive role of online teaching platforms in enhancing their academic performance and engagement. This finding is highlighted by Sweetman [60], who addressed the importance of establishing norms and expectations for students during synchronous class sessions and creating a framework for group work to enhance student engagement and performance.

Moreover, the results emphasized that students tend to engage and perform better in blended courses than in purely synchronous or asynchronous courses. The result is supported by Adnan and Anwar [39], who have pointed out that online learning may not be effective in underdeveloped countries, where most students face difficulties accessing the internet due to technical and economic challenges.

Further to that, the researchers stressed that online engagement could impact students' academic performance levels, and the success of this relationship is dependent on the integration of the online course, materials, instructor skills, and online teaching strategies. This finding aligns with previous research by Conijn, Beemt, and Cuijpers [58], who discovered a positive association between students' participation in a Massive Open Online Course (MOOC) and their MOOC completion. They also found that all MOOC activities were positively linked to final grades. Another study by Nieuwoudt [43] emphasized a significant relationship between the number of hours students spent on the Learning Management System (LMS) and their final grades. In contrast, Abou-Khalil et al. [51] focused attention on the importance of careful planning to support meaningful interactions and maintain online engagement. Similarly, Francescucci and Rohani [61] highlighted the positive impact of synchronous online learning on students' engagement, attendance, and participation.

In addition, the researchers confirmed the existence of students' positive attitudes and satisfaction are crucial predictors of their meaningful interaction, participation, and engagement in online learning courses. These results corroborate those of Rajabalee and Santally's [56] study, which found a significant and positive correlation between student satisfaction and engagement. Aristovnik et al. [54] also foregrounded the positive impact of online teaching methods on higher education students' attitudes and satisfaction. Likewise, Gopal, Singh, and Aggarwal [35] and Almusharraf and Khahro [53] stressed the importance of instructors' support in terms of course activities, assessment, teaching pedagogies, and delivery of online lectures in increasing students' attitudes, satisfaction, and engagement in their online learning. Aparicio, Bacao, and Oliveira [32] also pointed up the critical role of students' satisfaction with online learning systems in the success of e-learning.

Through examining students' attitudes towards online teaching platforms, the researchers conclude that students' dissatisfaction and their varied attitudes towards online teaching platforms based on their online learning experiences will provide higher education institutions in Palestine with new insights into the role of online teaching platforms and open the way for further contributions that focus on the development of students' online engagement and academic performance at Palestinian universities. We must also stress the strong correlation that was discovered between the instructor's role in online learning and students' engagement in online classes. With this, more specialized training in online teaching will contribute to better online engagement and academic performance, along with professional development, awareness programs, and the development of technical infrastructure problems.

It is important to note, however, that this study has several limitations. First and foremost, there are limitations in terms of the sample and size. To that end, the present research was carried out only at three Palestinian higher education institutions: Al Quds Open University, An Najah National University, and Arab American University. In addition, the study's population was limited to bachelor students of English specializations. Second, limitations in terms of the results. However, the current research investigated student attitudes towards the role of online teaching platforms in enhancing their engagement and academic performance level, and their perspectives towards the instructors' role in online teaching are examined. Nevertheless, the researchers confirm that these results can contribute to developing a full picture of what is happening in similar educational contexts. Third, limitations in terms of the existing literature.

The results discussed in this paper provide the following insights for future research. First, the researchers recommend exploring more recent systematic reviews that investigate student perceptions of online education and learner' teaching format preferences. Second, further studies involving more universities with samples from different specializations will confirm or contrast the findings of the current study.

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Teachers' Frequency of ICT Use in Providing Sustainable Opportunity to Learn: Mediation Analysis Using a Reading Database

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Abstract: As classrooms have become increasingly digitized, information and communication technology (ICT) has been frequently used by teachers. On that basis, whether teachers' ICT use could provide students with more and sustainable opportunities to learn (OTL) has aroused more attention in the relevant research field. However, there has been scarce evidence for teacher-related factors that elucidate the correlation between the ICT use of teachers and providing OTL in secondary education. Given this inefficiency of evidence, this study aimed to investigate the above correlation and explore the mediation effects of teachers' self-efficacy and teachers' flexible strategy use to solve individualized challenges (i.e., adaptive instruction). The data of 10,796 teachers in 389 secondary schools were analyzed using R based on a multilevel mediation model. As indicated by the results of this study, teachers achieved higher self-efficacy and adaptive instruction levels when ICT was used more frequently in reading classrooms, which would further enhance the provision of OTL for students. In addition, experienced teachers were better at facilitating adaptive instruction and self-efficacy using ICT. The above results could lay a solid foundation for future empirical studies to incorporate ICT in reading course design. Furthermore, it is imperative to carry out teacher training programs to improve teachers' beliefs and practices in providing OTL for better sustainable education in ICT education contexts.

Keywords: opportunity to learn (OTL); multilevel mediation; adaptive instruction; digital reading; PISA reading; sustainable education

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1. Introduction

In a digital environment, learning requires teachers to apply diversified information and communication technology (ICT) on a frequent basis to provide more accessible knowledge to learners [1–4]. Despite the ICT applications were designed and applied to the individualized needs of different students in the educational setting, the supportive and adaptive practices of teaching were highly demanded to guide students in the information processing while maximizing the benefits of digital learning [5]. Intending to fulfill lifelong learning opportunities prescribed by the 2030 Agenda for Sustainable Development, and to achieve the Goal 4 of quality education in Sustainable Development Goals [6,7], urging teachers to improve their ability to provide enriched learning opportunities to accommodate students to increasingly virtualized educational context, is highly essential.

Among the knowledge and skills required for the future development of an individual in the contemporary society, reading plays a fundamental role in the learning process [8]. Digital reading, which refers to the reading activity on ICT applications, requires higher levels of cognitive abilities to navigate, locate, process, and synthesize information than traditional pen-and-paper reading. Additionally, it allows more freedom and flexibility for students to explore digital information [9]. In this regard, learning digital reading seeks more opportunities to learn (OTL), as OTL increases the resources, connections, and feedback that guarantee the successful exploration of curricular knowledge. First proposed by John Carroll in 1963 in a model of school learning, OTL originally referred to the "actual time available to individual students to learn in view of the pacing of instruction (p. 733)" [10]. The OTL concept has long been focused on face-to-face classroom education and has been confirmed as a strong predictor of students' academic achievement [10]. The digital era extended the OTL definition as ICT would supplement more opportunities that might not be well covered by teachers, but it continued to highlight OTL in students' academic and overall development [11]. Since international educational databases such as Programme for International Student Assessment (PISA) reported measured outcomes of students' academic achievement and influencing factors, its survey through self-report questionnaires provided rich materials for secondary analysis. Secondary analysis using PISA data across variables might reveal the correlations that were not reported in the descriptive statistics of PISA report [12]. Previous secondary analysis using PISA has provided robust positive connections between OTL and adolescents' mathematics and science performance [13,14], and more relationships are to be tested specifically in other subjects, such as digital reading [15]. Since the main subject of the latest round of PISA, i.e., PISA 2018, focused on digital reading, its background questionnaire involved reading provided valuable information on reading-specific OTL and its influencing factors.

Up to now, there have been extensive research efforts on the positive connections between teachers' frequency of ICT use and OTL [16,17], which is worthy of test in digital reading. Although the frequency of ICT use by teachers does not directly lead to OTL, it is influenced by a collection of teacher beliefs and teaching practices. These beliefs and practices navigate the specific behavior of teachers to provide OTL, such as linking theory to daily experience and summarizing strategies [18]. By exploring the relationships between these teacher-related factors, it could be better explained how teachers utilize ICT applications to provide sustainable OTL for students.

The self-efficacy of teachers in instruction and adaptive instruction are two significant influencing factors for teaching effectiveness, especially in complex learning environments such as learning with ICT facilities [19]. At the secondary education level, the reduction of teacher self-efficacy has an adverse effect on the engagement of teachers in classroom teaching, the maintenance of teacher–student relationships, and the stability of career development [20]. Providing students with adaptive instruction contributed to more efficient classes where students gain more improvement. In combination, these two factors explained teaching effectiveness to a large extent. Currently, there is less clarity provided on how teachers apply ICT to formulate and adjust their teaching practice while improving the efficiency of classroom teaching. The mechanism of teachers' supportive behavior in the ICT-mediated reading class could be revealed by understanding relationships among teachers' ICT use, self-efficacy, and adaptive instruction. Therefore, the current study seeks to investigate the relationships between teachers' frequency of ICT use, in addition to the mediating effect of self-efficacy and adaptivity in the instruction in reading classes.

2. Literature Review

2.1. OTL

Originating from the International Education Association (IEA) investigations, the concept of OTL was a significant factor considered to investigate the impact of classroom teaching practice [21]. In John Carroll's model, OTL meant the time allocated for actual learning, while later definitions took OTL as content covered in sections of the implemented curriculum [22]. Considering both the time and content coverage for facilitating students learning, OTL was in essence closely connected to teacher practices [23]. This integrated definition was also adopted by the PISA, which defines OTL as teachers' frequency to summarize knowledge and link knowledge with real-life experiences through flexible classroom activities.

OTL could either be assessed by teachers' self-reports or students' reports [22]. In OTL assessment, it was surveyed frequently in international large databases, most notably PISA

2012, 2015, and 2018. PISA has incorporated OTL in the optional teacher questionnaire to investigate teachers' knowledge background, beliefs, and competencies in providing support for adolescent students [24]. Given the advantages of cross-regional large databases, the assessment of OTL in PISA has the potential for secondary analysis with other possible teacher-related factors.

Factors that contribute to more OTL have been discussed in worldwide educational contexts. School resources determine facilities and teacher qualities, which provided foundations of OTL [23]. In teaching practices, OTL entails the teachers' preparation before class, instructions in class, and feedback received through and after the courses [25]. Therefore, OTL is a multi-dimensional construct and is associated with facilities and pedagogy [26].

At present, OTL has also been recognized for decades as a key factor in sustainable student development in educational research, especially in face-to-face classes where students and teachers were directly and closely connected. Extant literature suggested a significantly positive impact of OTL on student achievement [27]. It was evidenced that middle school students were more likely to be well-supported in science learning and achieved better science performance in assessments when given more OTL [14]. Currently, OTL research revolves around STEM subjects, because researchers hold the belief that these disciplines which placed a strong emphasis on critical thinking and creativity merited additional OTL to enhance student learning results [28]. Comparatively, a significantly smaller number of studies focused on reading, as reading was more frequently viewed as a skill or literacy rather than a requisite subject [27]. Nevertheless, it has been consistently shown in research that OTL in reading is essential for understanding the effects of formal education [15]. Additionally, in OTL research, secondary schools received less attention than higher education and primary education [28,29], which made it necessary to investigate OTL specifically in the reading classes in secondary school by taking into account the characteristics of different educational levels.

As digital education emerged, where ICT was applied in the classrooms to allow students more freedom for exploration, more importance was attached to OTL [30]. A growing body of research has recently started to examine OTL in the context of digitization. According to researchers, ICT tools would improve the diversity of learning chances [31]. Differently, some researchers warned against a potential loss of control as instruction with more freedom was granted [32]. Given the mixed results, it was necessary to conduct further explorations in diversified educational settings.

2.2. Teachers' ICT Use in the Digital Reading Classroom

The term "teachers' ICT use" describes how teachers employ ICT resources to facilitate learning [20]. The use of ICT by teachers might provide students with more sustainable resources for learning and promote class involvement, both of which had a favorable impact on academic performance [33]. ICT accessibility or use and student learning have not, however, been consistently linked by empirical studies [34]. Although the bulk of studies came to the same conclusion—that ICT use helps students' reading performance—there were several studies that arrived at the opposite conclusion [35]. For instance, a meta-analysis examining reading media disclosed that frequent ICT reading would lead to decreased reading comprehension [36]. These results revealed that the association between ICT use and academic achievement was far more complicated and took into account aspects other than just access and use [37]. Additionally, a number of researchers contended that incorporating ICT into teaching methods has numerous advantages for students, particularly the enhancement of their learning opportunities in general literacy, such as reading [19].

For the sustainable development of future generations in this digital era, teachers are required to provide more resources by systematically integrating ICT into course design [38]. Increasing demands for teachers' ICT use in educational settings have led to the development of the technological, pedagogical, content knowledge (TPACK) framework, which prescribed the knowledge and competence of teachers to integrate ICT effectively into classroom practice [39]. At present, a majority of teachers needed assistance in improving their ICT literacy to teach reading, as evidenced by their opposition to integrating smart devices into reading classrooms and their feelings of uneasiness when using ICT devices to teach reading. These difficulties in integrating smart education into teaching practice would further reduce teachers' self-efficacy in smart education contexts.

ICT-mediated reading activities were built on the findings of numerous research that indicated utilizing ICT in the classroom aided adolescents in achieving their aim of successful reading [40–42]. Although teachers performed the role of agents who selected when and how to use all ICT devices, the process of teachers' instructional support using ICT has attracted far less attention in research than students' reading accomplishment [43]. Research on teachers' ICT use was, therefore, required to address technological integration while working toward curriculum integration with technology [44].

When incorporating ICT applications into school education, adaptive instruction that focused on each student's unique reading issues attracted more attention, because distinct individual features had a significant impact on the reading process. However, functions provided by ICT applications could not achieve their maximized positive effect without teachers' adaptive instruction to balance group learning context and individual needs [45]. Digital reading is more subjective and associated with more individualized cognitive activities [46], which further requires teachers' competence to coordinate learning activities in ICT-mediated reading courses. It was necessary to examine the linkages between OTL and other teacher-related elements to gain a better knowledge of how teachers provide OTL to students in reading classes [47].

2.3. Teachers' Self-Efficacy and Adaptive Instruction

The self-efficacy of teachers and their instruction adaptation were all considered significant teaching qualities needed to effectively support student development [46]. Self-efficacy paid attention to the motivational aspect of teachers' beliefs to educate students well, while adaptive instruction focused on the flexibility of teachers in varied instructional requirements. They collaboratively built up a student-friendly classroom for the learning of reading where students might benefit from the supportive environment.

In the context of digitized education, the definition of teachers' self-efficacy was extended to the confidence in teaching subject knowledge and classroom management. Higher levels of teachers' self-efficacy meant teachers' stronger confidence to keep pace with the times and develop a strong sense of efficacy in combining ICT with teaching. Among the contributors to teachers' efficacy, the years of teaching experience exerted a weak yet positive effect [47].

In regard to reading, teachers' self-efficacy referred to teachers' confidence in their ability to successfully guide students to fulfill reading tasks and exert a positive influence on students' reading ability. It was motivated by teachers' context-related appraisals to engage students in current reading activities [48]. Teacher self-efficacy played a role in encouraging teachers to guide students through the reading process, assisting them to overcome the obstacles to learning, and inspiring them to engage in learning. In general, there remained positive findings on the influence of ICT use on teachers' self-efficacy [45,49]. Nevertheless, most of these discoveries were based on general classrooms without specific disciplines or only within STEM subjects. Therefore, it remained debatable whether these findings applied to reading.

Encouraged in the context of digital learning, teachers' adaptive instruction is a type of flexible instruction strategy that makes changes to teaching contents and methods to provide instruction in a way that suits students' needs without reducing efficiency and effectiveness in teaching [50]. Rising computer-based educational systems have focused on adaptive instruction through algorithms, but in classroom practice, teachers' adaptive instruction is equally important to facilitate students' comprehension [24]. Usually understood as teachers' decision-making in classes, teachers' adaptive instruction required acute sensitivity to the classroom and students [51]. In reading, adaptive instruction was demonstrated as conducive to engagement in reading tasks [52]. After processing information from students' behaviors, teachers acted based on their decisions to re-design the tasks and instructions offered to students rapidly [53]. Existing studies focused attention mainly on a discussion about the benefits of adaptive instruction from the perspectives of students' learning process and outcomes. However, its direct relationship with teachers' connection with students was overlooked (e.g., providing OTL) [54]. By understanding the influences of adaptive instruction on the provision of OTL by teachers, the reading teachers could be better informed of their power of teaching practices with varied ICT applications.

2.4. Teachers' Teaching Experience and OTL

Teachers played an instrumental role in realizing OTL, as teacher characteristics and practices contributed to differentiated OTL levels [55]. According to some research, offering OTL required both pedagogical and subject expertise, which came from years of teaching experience. Therefore, novice teachers and experienced teachers might exhibit different patterns when providing OTL to students, thus yielding different results [56]. To help students understand, teachers could, for instance, modify or annotate their course materials using what they have learned from teaching.

The amount of OTL given to students was also observed to differ between novice and experienced teachers in terms of teacher autonomy. Less-experienced teachers preferred to lecture according to their prepared materials in both traditional and online learning environments, while more experienced teachers adapted their lesson plans in response to instant student feedback [57]. In this regard, novice teachers might fall short with their adaptive instructions.

Teaching experiences in virtualized educational contexts would increase the gap between novice teachers and experienced teachers when providing OTL, primarily because of teachers' experience integrating ICT applications into course contents [58]. Young teachers were more likely to simply rely on ICT, and less of their attention was paid to interactions between students. Nevertheless, questions remained about whether novice and experienced teachers would differ in terms of the influence of ICT use on digital reading performance.

Based on the literature review above, the following three research questions were proposed.

Research question 1. What is the relationship between teachers' frequency of ICT use and providing OTL?

Research question 2. How do teachers' self-efficacy and adaptation of instructions influence the relationship between teachers' frequency of ICT use and OTL?

Research question 3. Would these relationships be different between novice teachers and experienced teachers? If so, how?

Corresponding hypotheses were put forward based on existing evidence.

Hypothesis 1. *Teachers' higher frequency of ICT would lead to more frequent provision of OTL in reading classes.*

Existing evidence has proven a correlation between the frequency of teachers' ICT use and the frequency of OTL provision [30]. This study intended to explore this relationship in a large database regarding reading and confirmed its generality in secondary education.

Hypothesis 2. *Teachers' self-efficacy mediated the relationship between teachers' ICT use and their provision of OTL.*

There are empirical studies showing that frequent ICT use by teachers contributes to a higher level of self-efficacy in classroom teaching [48]. Increased self-efficacy of teachers could further increase the frequency of OTL provision. Given these two correlations, the mediation effect is worth testing.

Hypothesis 3. *Adaptation of instruction mediated the relationship between teachers' ICT use and their provision of OTL.*

More ICT use would contribute to a higher level of instruction adaptation [33], which is closely related to flexibility in classroom activities and teaching strategies. Such flexibility guaranteed students' comprehension of taught contents to a large extent [24].

Hypothesis 4. *Experienced teachers would perform better in transforming ICT use to OTL for students.*

A case study in a Chinese university suggested that experienced teachers enjoy more autonomy when using ICT [58]. With more adaptivity and autonomy, experienced teachers might better utilize ICT resources and create more learning opportunities, at least compared to novice teachers. Whether this could be applied to secondary students is tested in this study.

3. Methods

3.1. Data

This study utilized the PISA 2018 database, which provided rich contextual information to examine the influences of teacher-related factors on OTL [59]. PISA adopted a two-stage sampling procedure, with the random selection of schools before the random sampling of classes. Since PISA targeted 15-year-old students who were at the end of their voluntary education, investigations were conducted in secondary schools. A total of 10,796 teachers from 389 schools in the regions of Hong Kong, Macau, and Chinese Taipei were extracted from the database. These three regions were selected because they share a similar social development status, thus avoiding occasionality in results from only one region while freeing us of biases related to economic and cultural backgrounds [60]. These reading teachers were offered PISA 2018 teacher questionnaires to collect information about their educational and working backgrounds, classroom practices, and teaching beliefs; this questionnaire ought to provide additional evidence regarding their students' reading performance.

3.2. Variables

Five main variables were selected from the teacher questionnaire of PISA 2018 for analysis, of which year of work experience is used to recognize novice teachers and experienced teachers. The frequency of teachers' ICT use is taken as the independent variable, while the frequency of providing opportunities to learn for students is the dependent variable. Both teachers' self-efficacy in instruction and teachers' adaptive instruction were potential mediating variables.

Year of work experience as a teacher. PISA 2018 surveyed the years of experience in working as a teacher in the teacher background questionnaire. Research has indicated that teachers with more than five years of teaching experience would show a better perception of students' needs, design appropriate educational activities, and manage classroom order well [20]. Teachers who had five or less than five years of work experience were, therefore, regarded as novice teachers, compared to experienced teachers who had worked for more than five years.

Frequency of teachers' ICT use in classrooms (TCICTUSE). The frequency of teachers' ICT use was a derived variable in PISA, consisting of 14 items representing the different types of ICT applications in classrooms. Each item was rated by the corresponding yes/no answer to the question "During the last month, did you use any of the following digital devices?". All answers were processed officially by PISA and resulted in a derived, continuous variable.

Frequency of providing opportunities to learn in reading comprehension (TCOTLCOMP). In PISA, OTL is connected closely with the types and frequency of activities that engage students' overall comprehension ability in reading [61]. The frequency of providing opportunities to learn for students is also a derived variable based on teachers' responses to the question "How often do you teach the following aspects of reading comprehension in your lessons?". The aspects included cognitive support that facilitated reading comprehension. Of the 4 items (see below in Table 1) that constituted this variable, each item was scaled ranging from "never or almost never" to "every lesson or almost every lesson".

Table 1. Items of the derived variables.

Variable	Item	Scale
TCICTUSE	1. Tutorial software or practice programs 2. Digital learning games 3. Word-processors or presentation software 4. Spreadsheets 5. Multimedia production tools 6. Concept mapping software 7. Data logging and monitoring tools 8. Simulations and modeling software 9. Social media 10. Communication software 11. Computer-based information resources 12. Interactive digital learning resources 13. Graphing or drawing software 14. E-portfolios	1 = Yes 2 = No
TCOTLCOMP	1. Summarizing strategies 2. Connecting texts with prior content knowledge 3. Monitoring comprehension 4. Adapting the mode of reading depending on reading purposes	1 = Never or almost never 2 = Some lessons 3 = Many lessons 4 = Every lesson or almost every lesson
SEFFINS	1. I can craft good questions for my students 2. I can use a variety of assessment strategies 3. I can provide an alternative explanation for example when students are confused 4. I can implement alternative instructional strategies in my classroom	1 = Never or almost never 2 = Some lessons 3 = Many lessons 4 = Every lesson or almost every lesson
ADAPTINSTR	1. I tailor my teaching to meet the needs of my students 2. I provide individual help when a student has difficulties understanding a topic or task 3. I change the structure of my lesson on a topic that most students find difficult to understand 4. I provide individual support for advanced students	1 = Never or almost never 2 = Some lessons 3 = Many lessons 4 = Every lesson or almost every lesson

Teacher's self-efficacy in instruction (SEFFINS). Teachers' self-efficacy survey in PISA assessed teachers' beliefs in using strategies to help students develop their learning ability in reading. The assessed beliefs included crafting questions, providing assessment strategies, giving alternative explanations, and offering alternative instructional strategies. Each assessed aspect was shown as a separate item in the questionnaire, with the same four scales from "never or almost never" to "every lesson or almost every lesson".

Teacher's adaptive instruction (ADAPTINSTR). In PISA, teachers' adaptation of instruction was understood as teachers' flexible strategy use to solve individualized challenges faced by students. The assessed aspects include tailoring the teaching, providing individual help, and adaptively changing the topic of instruction, which evidenced teachers' adjustment of teaching strategies to ensure comprehension of the majority of students.

All items of the derived variables are listed in Table 1.

All derived variables were assessed reliability by PISA to ensure the items could effectively represent the corresponding latent variable and be appropriate for further analysis. The values of Cronbach's alpha which indicated reliability were listed in Table 2, and they all indicated acceptable reliability ($\alpha > 0.7$).

Table 2. Cronbach' alpha of the derived variables.

Region	TCICTUSE	TCOTLCOMP	SEFFINS	ADAPTINSTR
Chinese Taipei	0.907	0.870	0.785	0.806
Hong Kong	0.866	0.861	0.737	0.704
Macau	0.900	0.864	0.768	0.763

3.3. Modeling

A multilevel mediation model was adopted for the current analysis. In a clustered educational context, where teachers are nested in schools and schools are located in different regions, the effects of schools and regions might be apparent in individual teachers. To account for the differences between schools and regions, a multilevel mediation model was used.

Prior to the primary analysis, all data were pre-processed using SPSS 25.0.

First, expectation maximization (EM) was used to process all missing data. Using iterative expectation (E) and maximization (M) phases, the EM imputation generates maximum-likelihood estimates of the original data and produces an estimated value for each missing value in the original dataset. Second, standardization was carried out using Z scores to make sure that all data were assessed on the same scale.

The mediation analysis was performed in the lavaan package of R based on the structural equation modeling approach. For this study, a multilevel mediation model that incorporated two potential mediators was adopted, suggesting two parallel mediation paths of "X-M1-Y" and "X-M2-Y". The hypothetical figure is drawn as follows (Figure 1):

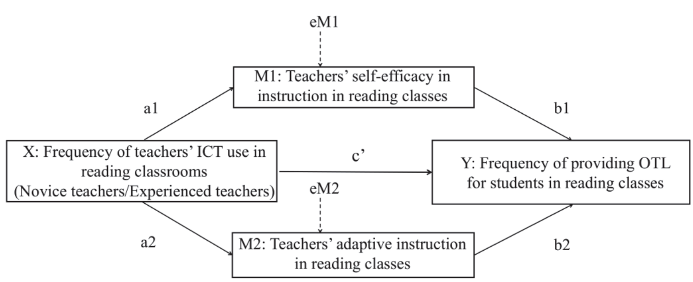

Figure 1. The hypothesized model.

In this model, each path is named according to the correlated relationships it represents. a1 and a2 represent the coefficients of influence from X to M1 and M2, respectively. b1 and b2 refer to the coefficients of influence from M1 and M2 to Y. c′ represents the direct effects, while a1b1 and a2b2 represent two parallel mediation effects. The sum of the direct and indirect effects of X on Y is used to determine the effects of X overall. The statistical model's Equations are constructed in the following method to measure these effects:

$$M1 = i_{M1} + a1X + eM1 \quad (1)$$

$$M2 = i_{M2} + a2X + eM2 \quad (2)$$

$$Y = i_Y + c'X + b1M1 + b2M2 + eY \quad (3)$$

where

i_{M1}, i_{M2}, and i_Y are regression constants, and eM1 and eM2 are estimated errors.

4. Results

4.1. Descriptive Results, Model Fit and Intra-Class Correlation

Table 3 shows the descriptive results for the main variables in this investigation. Among the 10,796 teachers in the reading subject from Chinese Taipei, Hong Kong, and Macau, 6928 (64.17%) were female and 9398 (87.05%) teachers had more than five years' teaching experience. The mean and standard deviation (SD) of the frequency of teachers' ICT use, frequency of providing opportunities to learn for students, teachers' self-efficacy in instructional settings, and teachers' adaptive instruction were based on the standardized outcomes of all participating regions in PISA 2018, with zero suggesting a median level among all surveyed regions. Therefore, Chinese Taipei, Hong Kong, and Macau all showed a higher frequency of teacher ICT use levels than the average level, while the outcomes for frequency of providing opportunities to learn for students, teachers' self-efficacy in instructional settings, and teacher adaptation of instruction were comparatively lower than the average global level. This demonstrates that these three regions are highly equipped for ICT, while also showing that teaching practices in a digitalized environment require further development.

Table 3. Descriptive Statistics.

Region	Number of Teachers	Female Teachers (Percentage)	Experienced Teachers (Teaching Experience > 5 Years, Percentage)	Frequency of Teachers' ICT Use in Classrooms		Frequency of Providing Opportunities to Learn for Students		Teacher's Self-Efficacy in Instructional Settings		Teacher's Adaptation of Instruction	
				Mean	SD	Mean	SD	Mean	SD	Mean	SD
Chinese Taipei	4586	3252 (70.91%)	4113 (89.68%)	0.1441	0.8442	−0.0263	0.8491	−0.3283	0.7537	−0.5850	0.7166
Hong Kong	3387	2006 (59.2%)	3050 (90.05%)	0.2289	0.0673	−0.3427	0.7884	−0.7422	0.7209	−0.7254	0.5757
Macau	2823	1670 (59.16%)	2235 (79.17%)	0.4204	0.8499	−0.2268	0.8815	−0.3394	0.7464	−0.7666	0.7209
Total	10,796	6928 (64.17%)	9398 (87.05%)	0.2430	0.8122	−0.1780	0.8321	−0.4611	0.7366	−0.6765	0.6864

Model fit indexes were included to ensure the hypothesized model was valid and appropriate for the interpretation of further results. Model fits for Chinese Taipei (CFI = 0.996, TLI = 0.984, RMSEA = 0.060, SRMR = 0.013), Hong Kong (CFI = 0.964, TLI = 0.936, RMSEA = 0.062, SRMR = 0.015), and Macau (CFI = 0.979, TLI = 0.962, RMSEA = 0.078, SRMR = 0.008) all indicated a good fit, showing that the data supported the hypothesized model.

To determine whether a multilevel analysis was necessary to account for the between-school variation in individual teachers' teaching practices, the intra-class correlation (ICC) method was tested. The ICC values for the frequency of providing opportunities to learn for students were 0.0137, 0.0019, and 0.0316 for Chinese Taipei, Hong Kong, and Macau, respectively. This suggested no significant school-level differences in teachers' frequency of providing opportunities to learn for students, as an ICC value less than 0.1 indicated possibly unbiased results if school-level factors were not considered. However, to ensure precision and set the model in a realistic educational setting, a multilevel mediation model is still needed to incorporate the possible influence of schools [62]. All coefficients in the analysis were results that accounted for the influence of schools.

4.2. Total Effects

The estimated total effects are displayed in Table 4, which shows that there is a positive relationship between teachers' frequency of ICT use in classrooms and the frequency of providing OTL for students in all three examined regions in the hypothesized model. The unstandardized model coefficient (*B*) showed that with a 1-unit increase in the frequency of teachers' ICT use in reading classrooms, OTL was predicted to show an increase ranging from 0.3670 to 0.4770 unstandardized units in groups of novice teachers and from 0.3609 to 0.4620 in groups of experienced teachers. Regarding the standardized model coefficient (β), with a 1-unit increase in the frequency of teachers' ICT use, OTL would correspondingly increase by 0.3405–0.4720 standardized units among novice teachers, and by 0.3624–0.4589 standardized units among experienced teachers. The frequency of ICT use was, therefore, largely proven to contribute positively to OTL, with experienced teachers showing more OTL given more use of ICT applications in reading classrooms. The standard error from 0.0139 to 0.0598 was within the normal range. Moreover, a 95% confidence level (95% CI) was used to test the significance of the results; a 95%CI that did not contain zero within its range suggested significant results.

Table 4. The c path (The total effects).

Region	Teacher Type	*B*	95% CI	β	SE
Chinese Taipei	Novice	0.3670 *	[0.3400, 0.3940]	0.4031	0.0139
	Experienced	0.3609 *	[0.3320, 0.3898]	0.3624	0.0147
Hong Kong	Novice	0.3751 *	[0.2579, 0.4924]	0.3405	0.0598
	Experienced	0.3882 *	[0.3569, 0.4194]	0.3913	0.0160
Macau	Novice	0.4770 *	[0.4440, 0.5100]	0.4720	0.0167
	Experienced	0.4620 *	[0.4249, 0.4991]	0.4589	0.0189

Note. *: significant results.

4.3. Direct Effects

Direct effects were reported to assess the relationship between the frequency of teachers' ICT use in reading classrooms and the frequency of the provision of opportunities to learn for students, ruling out the influence of potential mediators. As is represented in Table 5, the frequency of teachers' ICT use in classrooms positively influenced the frequency of the provision of OTL for students among novice teachers, thus separating the influence from potential mediators; this was apparent in Chinese Taipei (β = 0.2210, 95% CI $\in$ [0.2020, 0.2380]), Hong Kong (β = 0.2434, 95% CI $\in$ [0.1831, 0.3532]), and Macau (β = 0.3630, 95% CI $\in$ [0.3450, 0.3890]). Similarly, in the group of experienced teachers, this relationship remained positively significant in Chinese Taipei (β = 0.2167, 95% CI $\in$ [0.1960, 0.2353]), Hong Kong (β = 0.2615, 95% CI $\in$ [0.2378, 0.2811]), and Macau (β = 0.3522, 95% CI $\in$ [0.3303, 0.3789]). These findings suggested that teachers' ICT use was correlated with OTL in digital reading classes, regardless of the levels of teacher self-efficacy, adaptive instruction, and work experiences.

Table 5. The c' path (from frequency of teachers' ICT use in reading classrooms to frequency of providing opportunities to learn for students).

Region	Teacher Type	*B*	95% CI	β	SE
Chinese Taipei	Novice	0.2200 *	[0.2020, 0.2380]	0.2210	0.0093
	Experienced	0.2158 *	[0.1960, 0.2353]	0.2167	0.0099
Hong Kong	Novice	0.2682 *	[0.1831, 0.3532]	0.2434	0.0434
	Experienced	0.2594 *	[0.2378, 0.2811]	0.2615	0.0111
Macau	Novice	0.3670 *	[0.3450, 0.3890]	0.3630	0.0112
	Experienced	0.3546 *	[0.3303, 0.3789]	0.3522	0.0124

Note. *: significant results.

4.4. Mediation Effects

Paths of mediation are listed in Table 6. Notably, except for the fact that teachers' frequency of ICT use did not significantly affect novice teachers' self-efficacy in instruction in Hong Kong, all other mediation paths suggested significantly positive results ($p < 0.05$). In other words, teachers' frequency of ICT use significantly influenced adaptive instruction in all examined regions, as well as in both novice and experienced teachers' groups. In addition, both self-efficacy in instruction and adaptive instruction contributed to OTL in reading classes.

Table 6. The mediation paths.

Path		Region	Teacher Type	β	p	SE
TCICTUSE	→SEFFINS (a1)	Chinese Taipei	Novice	0.0736	0.0000 ***	0.0150
			Experienced	0.0660	0.0000 ***	0.0160
		Hong Kong	Novice	0.0346	0.5680	0.0604
			Experienced	0.0871	0.0000 ***	0.0176
		Macau	Novice	0.0642	0.0007 ***	0.0192
			Experienced	0.0654	0.0022 **	0.0218
	→ADAPTINSTR (a2)	Chinese Taipei	Novice	0.3070	0.0000 ***	0.0144
			Experienced	0.3101	0.0000 ***	0.0150
		Hong Kong	Novice	0.3213	0.0000 ***	0.0538
			Experienced	0.3370	0.0000 ***	0.0169
		Macau	Novice	0.2720	0.0000 ***	0.0182
			Experienced	0.2490	0.0000 ***	0.0208
SEFFINS	→TCOTLCOMP (b1)	Chinese Taipei	Novice	0.6450	0.0000 ***	0.0089
			Experienced	0.6433	0.0000 ***	0.0094
		Hong Kong	Novice	0.6872	0.0000 ***	0.0385
			Experienced	0.6700	0.0000 ***	0.0103
		Macau	Novice	0.6200	0.0000 ***	0.0107
			Experienced	0.6314	0.0000 ***	0.0080
ADAPTINSTR	→TCOTLCOMP (b2)	Chinese Taipei	Novice	0.3270	0.0000 ***	0.0093
			Experienced	0.3329	0.0000 ***	0.0100
		Hong Kong	Novice	0.2281	0.0000 ***	0.0469
			Experienced	0.2119	0.0000 ***	0.0103
		Macau	Novice	0.2530	0.0000 ***	0.0113
			Experienced	0.2626	0.0000 ***	0.0124

Note. **: $p < 0.01$; ***: $p < 0.001$.

Indirect effects, or mediation effects, are reported in Table 7. The results suggested that both teachers' self-efficacy in instruction and adaptive instruction were strong mediators between teachers' ICT use and providing OTL, except for novice teachers in Hong Kong, who failed to transform ICT use into self-efficacy. Comparatively, teachers' adaptive instruction displayed a larger standardized coefficient than teachers' self-efficacy in instruction, across regions and teacher groups. The proportion of mediation from 23.00% to 40.20% suggested medium-to-large effect sizes. Comparatively, the mediation effects were less evident in novice teacher groups compared to experienced teacher groups. A summary of the path coefficients is also presented in the figures of the full models for novice teachers and experienced teachers, respectively (Figures 2 and 3). Chinese Taipei, Hong Kong, and Macau were abbreviated as TAP, HKG, and MAC following PISA official reports. The "*" in the figures indicates significant results.

Table 7. The mediating effects.

Region	Teacher Type	M1 (a1b1)				M2 (a2b2)				Proportion
		B	95% CI	β	SE	B	95% CI	β	SE	
Chinese Taipei	Novice	0.0473 *	[0.0284, 0.0662]	0.0475	0.0096	0.1000	[0.0893, 0.1110]	0.1000	0.0055	0.4010
	Experienced	0.0422 *	[0.0223, 0.0622]	0.0424	0.0102	0.1028	[0.0912, 0.1143]	0.1032	0.0059	0.4020
Hong Kong	Novice	0.0262	[−0.0638, 0.1161]	0.0459	0.0238	0.0808	[0.0399, 0.1216]	0.0733	0.0208	0.2851
	Experienced	0.0579 *	[0.0350, 0.0808]	0.0117	0.0584	0.0708	[0.0609, 0.0808]	0.0714	0.0051	0.3316
Macau	Novice	0.0403 *	[0.0169, 0.0636]	0.0398	0.0119	0.0696	[0.0586, 0.0806]	0.0689	0.0056	0.2300
	Experienced	0.0416 *	[0.0149, 0.0682]	0.0413	0.0136	0.0658	[0.0535, 0.0782]	0.0654	0.0063	0.2325

Note. *: significant results.

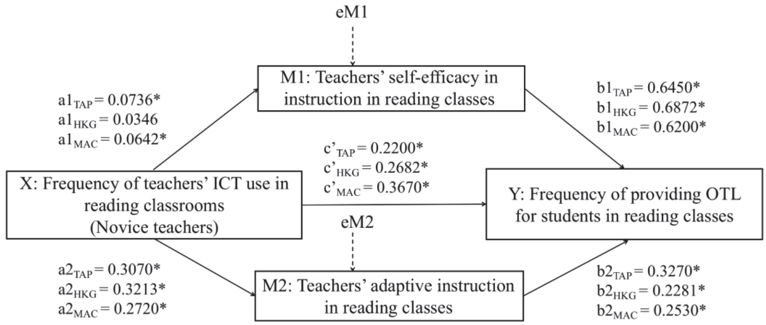

Figure 2. Path coefficients of the full model for novice teachers. Note. *: significant results.

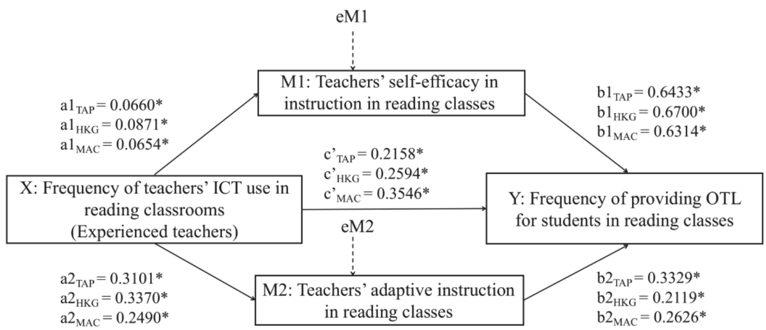

Figure 3. Path coefficients of the full model for experienced teachers. Note. *: significant results.

5. Discussion

This study advances the body of knowledge on how secondary school teachers use ICT to provide OTL for teaching reading. Among a bundle of studies investigating teachers' ICT use and students' academic performance, this article discusses the teaching beliefs and practices of entitling students to OTL, which enables young generations to develop reading abilities.

5.1. Teachers' ICT Use and OTL

The positive correlation between the frequency of teachers' ICT use and teachers' frequency of providing OTL supports Hypothesis 1 and is in agreement with the existing finding that OTL ought to be promoted in a highly digitalized learning environment [14]. Teachers' frequent ICT use, as revealed in the total effects and the direct effects of the mediation model, would contribute to more OTL provided by teachers, even without the influence of teachers' efficacy and adaptive instruction. Consistent results across our three examined regions suggested that the positive correlation between the frequency of teachers' ICT use and teachers' frequency of providing OTL was common. In addition, the results further confirmed the accessibility of the OTL concept in the online learning context, where time and content coverage together explained students' OTL.

Admittedly, OTL provided by teachers and possessed by students was influenced by macro-influencing factors, such as economic, social, and cultural statuses (ESCS) [60]. Higher ESCS levels would lead to better academic performance through the lens of unequal opportunities, while the use of technology would help narrow the gap of such inequality if it is well guided by teacher support [63]. However, micro-level factors also counted for opportunities students would receive in classroom teaching. Students' OTL, in accordance with what Schmidt and fellow researchers have discovered [26], was largely influenced by teacher practice and disciplinary climate, which were also applied in digitalized classrooms.

Evidence from investigations revealed two levels of instructional support for digital reading. Fundamentally, the level of technology integration refers to the mere adoption of ICT in the classroom, whereas teachers at this level often failed to integrate ICT with classroom activities, resulting in undesirable outcomes for students' digital reading performance. The second level refers to the curricular integration in which teachers were proactive and strategic in guiding students to process the information and fulfill the prescribed tasks in digital environments [9].

To explain the correlation between the frequency of teachers' ICT use and teachers' frequency of providing OTL, it is apparent that ICT use by teachers would save time on procedural routines that ensure comprehension of the majority of students. In addition, ICT use equips teachers and students with more accessible information to summarize, and more flexible tasks to switch according to the modes of the class. On this basis, richer contents and individualized learning processes were offered to larger quantities of students, which constituted the core of OTL expected by students.

Even though teachers' ICT use was demonstrated to contribute more OTL, appropriate teaching strategies are still needed to support the benefits of ICT, thus confirming the results in other studies of ICT and Carroll's model that students' learning depends partly on factors controlled by teachers [10]. OTL is provided with the final aim of developing students' learning outcomes and learning abilities. As a rising form of literacy that largely influences adolescents' future development [18], digital reading is more emphasized in OTL [15,64,65]. The existing literature linking OTL to students' reading performance has also highlighted the importance of investigating OTL in reading [15]. The same held true in the digital learning context, where OTL assumed more considerable importance.

5.2. Frequency of ICT Use, Self-Efficacy in Instruction, and Adaptive Instruction in Reading

According to the current findings, ICT use enhanced self-efficacy of both the novice teachers and experienced teachers in instruction and adaptive instruction in reading, across Macau and Chinese Taipei. The findings only partially matched H2 as Hong Kong novice teachers did not successfully transform their frequency of ICT use into the development of their self-efficacy. This research extended the correlation between ICT use and teachers' self-efficacy to the field of reading, and this subject-specific research allowed the disclosure of some unique findings in contrast to general discussions on teacher self-efficacy development. With the exception of Hong Kong in this study, all results have indicated that using ICT applications in reading classrooms more frequently increased teachers' levels of self-efficacy, both inexperienced and experienced. This aligned with the former investigations of mathematics teachers who gained more self-efficacy in teaching as they were more familiar with ICT in teacher training programs [49]. However, the results obtained from novice teachers in Hong Kong questioned the universality of the positive relationship between ICT use and teachers' self-efficacy. Surprisingly, more access to and use of ICT did not bring these teachers evident progress in self-efficacy, which might be attributed to teachers' anxiety over balancing classroom management and ICT use management [45]. Novice teachers were restrained by more complex elements in classroom settings in ICT educational setting, which inhibited teachers' confidence in providing OTL that sustained adolescents' long-term development. These contradictory results might also be rooted in teachers' values, which viewed ICT as a required but unfavorable application [30].

Hypothesis 3 was upheld, as more frequent ICT use would indicate better adaptive instruction among teachers. This implied that teachers' ICT use largely influenced teachers' beliefs and behaviors, before it could contribute to teachers' providing OTL, in accordance with previous studies [44]. In addition, any changes in the educational level were the results of a collective of individual, school, and regional factors [66]. This further demonstrates the necessity to conduct a multilevel analysis to account for potential influences from school-level differences. There are arguments claiming that ICT use could cause uncertainties among teachers, but this study found that adaptive instruction using ICT among teachers would relieve students' anxiety by receiving more learning opportunities, which are in turn related to increases in reading achievement [67].

Considering the positive effects of ICT use on teachers' practices that benefit students, it is worth exploring teachers' detailed use of teaching practices [68]. Therefore, school management staff should not only strengthen teachers' professional skills training but also pay attention to teachers' internal cognition related to teaching matters, striving to improve teachers' self-efficacy. Teacher education has even more firmly emphasized the use of such technologies in a meaningful way in educational settings [69].

5.3. Novice Teachers and Experienced Teachers in Using ICT

The data corroborated Hypothesis 4 and were in line with existing research that has discovered that teachers experience transitions in cognitive activity (such as self-efficacy) and classroom practice (such as adaptive instruction) as they progress from novice to experienced teachers [70]. Particularly in the area of ICT integration, both novice and experienced teachers could benefit from a variety of ICT applications to promote their efficacy and adaptivity in the classroom, demonstrating the advantages of integrating ICT into reading courses to provide sustainable and high-quality education to students. Nevertheless, while utilizing ICT in the classroom, novice teachers were less able to fully utilize ICT applications to improve their self-efficacy in teaching, and they were less skilled at using ICT to adjust their teaching practice adaptively in response to student needs. This was corroborated by existing discovery that inexperienced teachers, lacking confidence in the learning process of their students, tended to follow a predetermined form of instruction, and frequently gave lessons based on their preparation rather than the immediate needs of the students in the classroom [57]. Though such fully prepared instructions might be effective in ensuring rich contents and consistent flows in reading classrooms, they might also inhibit students' OTL, as only limited freedom to explore and targeted information were provided.

The discrepancy in self-efficacy and adaptive instruction between novice teachers and experienced teachers could be attributed to a fear of losing control of classroom management. Introducing ICT into reading courses would increase these uncertainties, as some of the knowledge was imparted to students through ICT facilities and the process was not under the complete control of teachers [58]. Even when less-experienced teachers are inclined to use ICT more often and for more diversified purposes, they are disadvantaged in their competence in balancing ICT use and classroom management [19]. Therefore, to develop novice teachers' ICT competence, support should be provided in guiding teachers to systematically integrate ICT into course design, thus potentially reducing teachers' fear of flexibly adapting their instruction [71].

6. Conclusions

This study aimed to investigate the influence of the ICT use by teachers on teachers' beliefs and behaviors that might provide more opportunities for students' sustainable development in the digitalized environment [72]. Three major discoveries were revealed by the multilevel mediation model constructed and validated in this study: (a) teachers' more frequent use of ICT applications would provide more OTL for students in reading classrooms; (b) both teachers' self-efficacy in instruction settings and their adaptive instruction mediated the relationship between the relationships of teachers' ICT use and teachers' providing OTL; (c) experienced teachers were better at transforming the benefits of ICT use to self-efficacy and adaptive instruction, and thus provide more OTL for students. These findings encouraged secondary teachers to utilize ICT in classrooms more frequently, while suggesting cultivating self-efficacy and adaptive instruction as they developed their ICT competence.

The current study is insightful regarding teachers' required qualities when adopting ICT in classrooms in addition to ICT competence in designing sustainable ICT-mediated reading courses and relevant teacher training programs. Accessing more OTL through the courses is one prerequisite for students' sustainable development in increasingly diversified education resources. First, teachers should receive training in advance on how to apply ICT more regularly and more diversely to provide students with more diverse, equal, and universal access to sustainable learning opportunities. Different ICT facilities might target a larger population of students, who might benefit from their preferred method of ICT integration. Second, in teachers training programs, teachers' self-efficacy in teaching in a digital environment should be given more attention in teachers' training programs so that they not only learn how to operate the ICT tools, but also gain knowledge about systematically integrating different types of ICT into reading course design. Third, schools and educational management administrators should avoid evaluating teachers' ICT use only from students' academic performance, and instead incorporate teachers' pedagogical beliefs and classroom practice as additional assessments to maximize the effects of ICT in creating high-quality and high-efficiency classrooms.

This study has several limitations that should be considered when interpreting its results. First, this data-driven study was reliant on the data from PISA 2018, and the secondary analysis lacked specific classroom context information; however, the latter did offer more opportunities to explore large-scale and cross-regional data that might yield more general conclusions. Second, since PISA adopted self-reported questionnaires to assess teachers' frequency of ICT use in reading classrooms, teacher self-efficacy, teachers' adaptive instruction, as well as teachers' frequency, biases might arise from teachers' perceptions of their abilities and classroom activities. Future empirical studies are needed to assess the quality of teachers' providing OTL actions in specific classroom contexts through observed classroom activities, as well as investigate how students perceive teachers' providing OTL in the E-learning environment. Additionally, future classroom studies could evaluate how well students perceive OTL their teachers offer via ICT applications, thereby creating recommendations for enhancing student–teacher interactions with technology.

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Article

The Cost of Caring: Compassion Fatigue Is a Special Form of Teacher Burnout

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Abstract: Compassion fatigue is a unique form of burnout that can seriously negatively impact both teachers' development and students' growth. A questionnaire survey was carried out among 1558 primary and secondary school teachers from 28 provincial administrative regions by using the Professional Quality of Life Scale (Pro QOL-5), and the results showed that: (1) the quality of professional life of primary and secondary school teachers in China is at the medium level, and compassion fatigue above the mild level is widespread; (2) there are individual differences in teachers' compassion satisfaction and burnout. Teachers with more than 20 years of teaching experience at the senior title or above and college degree or below have higher levels of compassion satisfaction and lower levels of burnout. The level of compassion satisfaction is relatively high among teachers who are at school-level leadership or above and who are primary school teachers. The level of secondary trauma is relatively high among teachers in secondary schools and secondary vocational schools; (3) position (headteacher and class teachers), title (primary), and school type (secondary) have a significant influence on the degree of compassion fatigue. The findings suggest that compassion fatigue among primary and secondary school teachers needs urgent attention. By helping teachers identify compassion fatigue, learn self-care, adjust self-cognition, and clarify the boundaries of their professional competence, teachers' compassion fatigue can be prevented and alleviated.

Keywords: primary and secondary school; teacher; compassion fatigue; compassion satisfaction; burnout

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1. Introduction

Since the 1990s, the study of sustainable development strategies has become a common theme in social development research around the world. The sustainable development of society as a whole depends on the sustainable development of its basic cells, the individuals. The sustainable development of individuals cannot be achieved without education, and teachers play a fundamental and critical role in promoting sustainable human development. Across the globe, a growing number of countries are embarking on dramatic educational reforms that are expected to transform the current educational landscape and help students develop the knowledge, skills, and values needed for sustainable development.

Current educational reforms are more sensitive to the needs of learners than traditional ones and require teachers to adapt their teaching styles to meet those needs [1]. However, this requires teachers to have the resources and autonomy to meet the individual needs of their students, yet the lag in grassroots school management reforms has prevented teachers from practicing these reforms, including the deprivation of teachers' technical freedom to teach (deprivation of power over labor control) and the deprivation of educational cognition (deprivation of power to determine the pedagogical value of teachers' work). In addition, the arbitrary distribution of school work, the lack of teacher autonomy over their work, poor student quality, lack of parental support, and inadequate teacher training have led to high levels of stress in broad educational reforms, with some negative consequences for teachers [2]. When too many reforms are implemented too quickly, reforms can negatively affect the emotional well-being of educators [3]. A large Canadian survey revealed that 62% of teachers felt stress related to having to deal with student health and personal issues as educational reform moved forward, and since compassion fatigue can develop through the stress of wanting but not being able to help someone in distress [4], this may imply that educators may be more susceptible to compassion fatigue during the fast-paced educational reform process.

1.1. What Is Compassion Fatigue

Compassion fatigue is a relatively new concept in the field of psychology. It first appeared in the report on nurse burnout [5] and is regarded as a unique form of burnout. Figley (1995) defines compassion fatigue as "the behaviors and emotions that naturally arise from empathizing with a significant traumatic event during help, which results from the stress of wanting to help a traumatized or suffering person [6]." As with any other type of fatigue, compassion fatigue reduces the ability or interest of helpers in bearing the pain of others, so it is often used to describe "the cost of caring." It should be emphasized that compassion fatigue is not a pathological reaction but a "natural, predictable, treatable and preventable" response to a traumatic individual.

Compassion fatigue is considered to be the result of working directly with victims of disasters, trauma, or illness, especially in the healthcare industry [7]. Individuals working in other helping professions are also at risk for experiencing compassion fatigue [4]. These include child protection workers, veterinarians [8], and teachers [6]. Teachers, as with medical workers, firefighters, police, social workers, and other personnel, are working to help others. Teachers are exposed to pressure sources for a long time in their work practice. They have to deal with various educational and teaching problems, establish and maintain a good relationship between teachers and students, and take the initiative to give more care and help to students, so they are prone to compassion fatigue.

1.2. The Clinical Symptoms of Compassion Fatigue

People who experience compassion fatigue may exhibit a variety of symptoms including lowered concentration, numbness or feelings of helplessness, irritability, lack of self-satisfaction, withdrawal, aches and pains, or work absenteeism. The clinical symptoms of compassion fatigue are similar to post-traumatic stress disorder, secondary trauma, vicarious (indirect) traumatization, burnout, etc. In order to better recognize and understand the concept of compassion fatigue, Sun et al. (2011) compared and analyzed the relationship between these concepts and concluded that the essence of compassion fatigue is mainly manifested as follows: First, the clinical symptoms of helping people are similar to post-traumatic stress disorder [9]. They are not due to the traumatic event, but a prolonged contact with the traumatized person. Second, the root cause of compassion fatigue in the helping group lies in the active payment of empathy and other large amounts of psychological energy during the rescue process and thus encounters empathic stress [10]. This study holds that teachers' compassion fatigue is based on the premise that they actively give empathy to the real, implicit, or imaginary relief targets (students). In the process of providing material or emotional assistance to the relief targets (students), they suffer secondary trauma, which reduces their ability and interest in empathizing with the relief targets (students), the academic work burnout feeling emerges, and even changes in their original values and worldview occur, along with a series of physical and mental discomfort symptoms.

1.3. The Risk Factors of Compassion Fatigue

Several personal characteristics may lead to compassion fatigue. Overly conscientious individuals, perfectionists, and selfless individuals are more likely to suffer from secondary traumatic stress. Those who have low levels of social support or high levels of stress in personal life are also more likely to develop STS.

In addition, previous histories of trauma that led to negative coping skills, such as bottling up or avoiding emotions and having small support systems, increase the risk for developing STS [11]. Workers in fields where STS is most prevalent, such as healthcare, are more likely to suffer compassion fatigue due to organizational characteristics. For example, a "culture of silence" where stressful events such as deaths in an intensive-care unit are not discussed after the event is linked to compassion fatigue [12]. It may also be responsible for high rates of STS if people are not aware of symptoms and are not trained in the risks associated with high-stress jobs [13]. As the needy interact more, compassion fatigue becomes more intense. Because of this, people living in urban cities are more likely to experience compassion fatigue. People in large cities interact with more people in general, and because of this, they become desensitized toward people's problems. Homeless people often make their way to larger cities. Ordinary people often become indifferent to homelessness when they see it regularly [14].

1.4. The Compassion Fatigue among Teachers

In response to the changing landscape of post-secondary institutions, sometimes as a result of having a more diverse and marginalized student population, both campus services and the roles of student affairs professionals have evolved. These changes are efforts to manage the increases in traumatic events and crises [15]. Due to the exposure to student crises and traumatic events, student affairs professionals, as front-line workers, are at risk for developing compassion fatigue. Such crises may include sexual violence, suicidal ideation, severe mental health episodes, and hate crimes/discrimination. Student affairs professionals who are more emotionally connected to the students with whom they work and who display an internal locus of control are found to be more likely to develop compassion fatigue as compared to individuals who have an external locus of control and are able to maintain boundaries between themselves and those with whom they work.

The specificity of the object, process, nature, and purpose of teachers' work determines that teachers need to actively pay much emotion, care, and patience to students in their work. Empathy is a core professional competency of teachers [13]. Teachers with high empathy also tend to be more enthusiastic about their work and will provide more care, wisdom, passion, and quality instruction for their students. The capacity to accomplish these tasks lies in the individual teachers, but this resource may be gradually exhausted when teachers are overworked, and teachers' compassion cannot be satisfied [16]. Expressing empathy is a regular part of teachers' education and teaching process. If teachers devote a lot of empathy and other psychological energy to empathizing with students but fail to achieve a good empathy effect, they will quickly develop "compassion fatigue." Teachers experiencing compassion fatigue will undergo changes in physical, emotional, behavioral, cognitive, interpersonal, and professional performance, such as feeling tired, numb, or distant from students, being impatient or intolerant of student matters, having poor teaching work, and having a decreased sense of responsibility [3].

1.5. Prevention of the Compassion Fatigue

1.5.1. Mindfulness

Self-awareness as a method of self-care might help to alleviate the impact of vicarious trauma (compassion fatigue). Students who took a 15-week course that emphasized stress reduction techniques and the use of mindfulness in clinical practice had significant improvements in therapeutic relationships and counseling skills [17]. The practice of mindfulness according to Buddhist tradition is to release a person from "suffering" and to also come to a state of consciousness of and relationship to other people's suffering.

Mindfulness utilizes the path to consciousness through the deliberate practice of engaging "the body, feelings, states of mind, and experiential phenomena (dharma)." The following therapeutic interventions may be used as mindfulness self-care practices: somatic therapy (body); psychotherapy (states of mind); emotion-focused therapy (feelings); Gestalt therapy (experiential phenomena) [18].

1.5.2. Self-Compassion

In order to be the best benefit for clients, practitioners must maintain a state of psychological well-being [19]. Unaddressed compassion fatigue may decrease a practitioner's ability to effectively help their clients. Some counselors who use self-compassion as part of their self-care regime have had higher instances of psychological functioning [19]. The counselor's use of self-compassion may lessen experiences of vicarious trauma that the counselor might experience through hearing clients' stories. Self-compassion as a self-care method is beneficial for both clients and counselors.

1.6. The Aim of the Current Study

Compassion fatigue is a unique mental health issue that can occur after helping people by empathizing, caring, and helping others. In the helping profession, compassion fatigue as a particular kind of burnout is the price of caring. Teachers are exposed to stressors for long periods of time in their work practices, not only to deal with various educational and teaching issues, but also to establish and maintain good teacher–student relationships and take the initiative to give more care and help to students, so they are prone to the problem of compassion fatigue, which leads to inappropriate teacher behaviors and affects the professional ethics of teachers. Yet, this issue has not yet attracted attention in China. The current study, using the method of empirical research, investigates the current situation of compassion fatigue of primary and secondary school teachers in China. These are of great significance to enrich the current international research of compassion fatigue of teachers and prevent teachers' moral anomie due to compassion fatigue.

2. Methods

2.1. Participants

In the form of a web-based survey, this study used the cluster random sampling method to distribute the questionnaire and obtain responses from 1558 primary and secondary school teachers in 28 provinces, municipalities, autonomous regions, and municipalities directly under the central government of China, including Zhejiang, Hebei, Guangdong, Sichuan, Guizhou, Qinghai, and Xinjiang. Finally, 1527 valid questionnaires were obtained, with a valid return rate of 98.01%. Among the valid questionnaires collected, 831 (54.42%) were teachers in the eastern region, 696 (45.58%) were teachers in the midwestern regions; 552 (36.15%) were male teachers, 975 (63.85%) were female teachers; 572 (37.46%) were primary school teachers, 599 (39.23%) were secondary school teachers, 193 (12.64%) were ordinary high school teachers, 163 (10.67%) were secondary vocational school teachers; 192 (12.57%) teachers were in schools above the prefectural and municipal level, 434 (28.42%) were at the district and county level, 611 (40.01%) were in townships, and 290 (18.99%) were in rural areas.

2.2. Measures

2.2.1. General Materials

By referring to relevant literature and combining with the characteristics of teachers, a questionnaire of teachers' biographical information was prepared, which included items such as region, gender, teaching experience, teaching subject, title, position, education background, location of the school, and school type.

2.2.2. Professional Quality of Life Scale (Pro QOL-5)

The Professional Quality of Life Scale (Pro QOL-5) can be used to measure both positive (compassion satisfaction) and negative (compassion fatigue) aspects of compassion. Compassion fatigue is composed of two parts: burnout and secondary trauma. Burnout includes the typical symptoms of job burnout, such as frustration, anger, and depression; secondary trauma is a type of negative emotion caused by fear and work-related trauma. The entire questionnaire included 30 items divided into three sub-scales, compassion satisfaction (CS), burnout (BO), and secondary traumatic stress (STS), with ten items per sub-scale. The score was assessed on a 5-point Likert-type scale (1 = not at all, 5 = completely), and the five items of 1, 4, 15, 17, and 29 were reversed. The total score of each sub-scale $\leq$22 indicates low level; 23~41 indicates medium level, and $\geq$42 indicates high level. The total score of each sub-scale of risk values was: compassion satisfaction sub-scale score of 33 (25%) or below, burnout score of 26 (75%) or above, secondary trauma score of 17 (75%) or above [1].

The Professional Quality of Life Scale (Pro QOL-5) covers various types of occupations. When used to measure teachers' compassion satisfaction and compassion fatigue, only the word "helpers" in the original scale needs to be replaced by "teachers" in the original scale, and these changes do not need special permission from the test developer [20]. The structural validity of ProQOL-5 is supported by over 200 peer-reviewed articles, with evidence that over 100,000 articles and half of the 100 published research papers on compassion fatigue, secondary trauma, and vicarious traumatization use ProQOL-5 or earlier versions. The internal consistency α coefficient of the scale was: 0.88 for compassion satisfaction, 0.75 for burnout, and 0.81 for secondary trauma [20]. In this study, Cronbach's α coefficients of compassion satisfaction, burnout, and secondary trauma were 0.93, 0.85, and 0.81, respectively.

2.3. Procedure

In this study, a group test was conducted anonymously. Questionnaires were sent to the subjects through WeChat, QQ, Dingding, and Email with the consent of the subjects and the leaders of the unit, and the questionnaires were directly collected through the background of Wenjuanxing. SPSS25 statistical analysis software was used to measure the levels of compassion fatigue, burnout, secondary trauma, and compassion satisfaction, as well as the correlation between these phenomena, and to explore the compassion fatigue of teachers with different demographic characteristics (region, gender, teaching experience, position, etc.).

3. Results

3.1. The Compassion Fatigue among Primary and Secondary School Teachers

3.1.1. The Teachers' Scores on the Subscale of Professional Quality of Life Scale

According to the analysis of 1527 valid questionnaires (Table 1), it was found that the professional life quality of primary and secondary school teachers in China was at a medium level. The total score on the compassion satisfaction (CS) subscale was (36.23 $\pm$ 7.66), the number of people in the low-level group was 70 (4.58%), and the number of people in the medium- and high-level groups was 1457 (95.42%); the total score of the burnout (BO) subscale was (24.33 $\pm$ 6.58), and the number of people in the medium- to the high-level group was 932 (61.03%); the total score of secondary trauma (STS) was (25.37 $\pm$ 6.28), and the number of people in the medium- to the high-level group was 999 (65.42%). According to the above analysis, it can be found that Chinese primary and secondary school teachers' compassion satisfaction was at medium and high levels, while burnout and secondary trauma were at a medium level.

Table 1. Professional Quality of Life Scale subscale scores of primary and secondary school teachers and the number of people in each level group (*N* = 1527).

Subscale	Score (*M* ± *SD*)	Low Level (*N*)	Medium Level (*N*)	High Level (*N*)
Compassion fatigue	36.23 ± 7.66	70 (4.58%)	1092 (71.51%)	365 (23.90%)
Burnout	24.33 ± 6.58	595 (38.97%)	924 (60.51%)	8 (0.50%)
Secondary trauma	25.37 ± 6.28	528 (34.58%)	985 (64.51%)	14 (0.92%)

Note: ≤22 indicates low level; 23~41 indicates medium level; ≥42 indicates high level.

3.1.2. The Level of Compassion Fatigue among Teachers

According to the judgment criteria of mild, moderate, and severe compassion fatigue in the user manual of the occupational quality of life scale by Stamm (2010), if the total score of any subscale exceeds the critical value, it is mild compassion fatigue, and if the total score of any two subscales exceeds the critical value, it is moderate compassion fatigue. If the total scores of the three subscales exceed the critical value, it is severe compassion fatigue. Among the 1527 primary and secondary school teachers in this study, 111 (7.27%) had no compassion fatigue, 739 (48.40%) had mild compassion fatigue, 290 (18.99%) had moderate compassion fatigue, and 387 (25.34%) had severe compassion fatigue (Table 2).

Table 2. Analysis table of compassion fatigue among primary and secondary school teachers (*N* = 1527).

Degree	Score of Each Dimension	Number	Detection Rate %
No	CS ≥ 33 and BO ≤ 26 and STS ≤ 17	111	7.27%
Mild	CS < 33 or BO > 26 or STS > 17	739	48.40%
Moderate	Total score of any two subscales exceeds the critical value	290	18.99%
Severe	CS < 33and BO > 26 and STS > 17	387	25.34%

Note: CS means compassion fatigue, BO means burnout, STS means secondary trauma.

As shown from Table 2 and the detection map of compassion fatigue for primary and secondary school teachers (Figure 1), compassion fatigue was common among primary and secondary school teachers: 1416 teachers (92.73%) showed mild compassion fatigue or above, and 677 teachers (44.34%) showed moderate compassion fatigue or above.

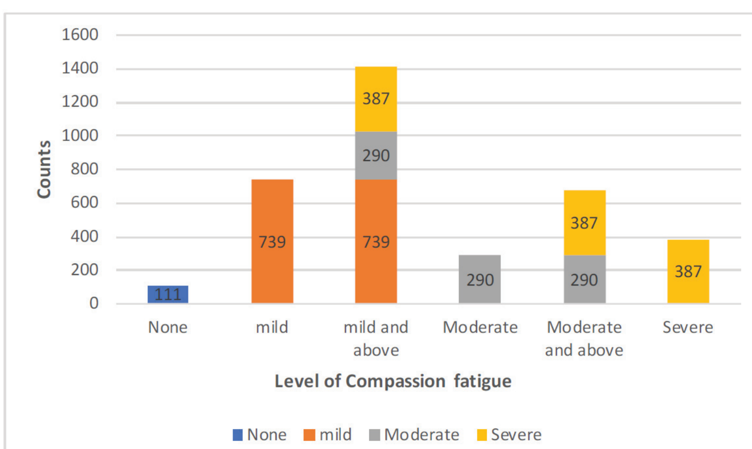

Figure 1. Results of compassion fatigue detection among elementary and secondary school teachers. The level of compassion fatigue of the teachers was divided into no detection, mild, moderate and

severe. The no detection level means the score of the teachers in the dimension of compassion satisfaction (CS) was higher than 33, burnout (BO) was lower than 26, and secondary traumatic stress (STS) lower than 17; the mild level means the score of the teachers in the dimension of CS was lower than 33, or BO was higher than 26, or STS higher than 17; in the moderate level means the score of the teachers in any two dimensions of professional quality of life scale was exceeds the critical value; in the severe level means the score of the teachers in the dimension of CS was lower than 33, BO was higher than 26, and STS higher than 17.

3.2. The Difference among CS, BO, and STS

Data from the questionnaires were processed by SPSS25, and independent sample *t*-tests and one-way ANOVAs were conducted with the subjects' biographical information as the independent variable and compassion satisfaction, burnout, and secondary trauma as the dependent variables. It was found that there were no statistical differences in empathy satisfaction, burnout, and secondary trauma among primary and secondary school teachers of different gender, teaching subject, and school location. The difference between teachers' compassion satisfaction in the eastern and western regions was marginally significant: eastern (36.57 ± 7.56) > midwestern (35.81 ± 7.77), $p = 0.054$; there was a statistically significant difference in the secondary trauma dimension: eastern (25.08 ± 6.41) < midwestern (25.73 ± 6.102), $p = 0.044$; there was no statistically significant difference in the burnout dimension. Table 3 shows the statistical differences in compassion satisfaction, burnout, and secondary trauma by teaching experience, position, title, education, and school category ($p < 0.05$).

Table 3. Differences in the dimensions of compassion fatigue among primary and secondary school teachers (N = 1527).

Item		*N*	Compassion Satisfaction (CS)		Burnout (BO)		Secondary Trauma (ST) (STS)	
			M	*SD*	*M*	*SD*	*M*	*SD*
teaching age	1	317	35.15	7.01	24.85	6.33	26.14	6.03
	2	231	35.57	7.72	25.06	6.85	25.39	6.57
	3	428	35.54	7.77	24.79	6.57	25.01	6.41
	4	551	37.66	7.72	23.38	6.51	25.21	6.17
F			10.383		6.240		2.184	
P			<0.001		<0.001		0.088	
Scheffe			1 < 4 ***, 2 < 4 **, 4 < 3 *** 3 < 4 ***		1 > 4 *, 2 > 4 *, 3 > 4 *			
Position	1	796	35.58	7.74	24.78	6.52	25.55	6.32
	2	482	35.57	7.39	24.87	6.62	25.45	6.31
	3	165	38.80	6.96	22.51	6.02	24.70	5.91
	4	84	41.11	7.15	20.54	6.11	24.55	6.36
F			21.475		16.387		1.355	
P			<0.001		<0.001		0.255	
Scheffe			1 < 3 ***, 1 < 4 ***, 2 < 3 ***, 2 < 4 ***		1 > 3 ***, 1 > 4 ***, 2 > 3 ***, 2 > 4 ***			
title	1	237	36.65	6.66	23.57	6.47	25.42	6.45
	2	365	34.45	8.10	25.85	6.66	26.19	6.39
	3	611	36.26	7.68	24.37	6.61	25.05	6.22
	4	314	37.92	7.42	23.07	6.15	25.02	6.05
F			12.120		11.620		2.954	
P			<0.001		<0.001		0.032	
Scheffe			2 < 1 **, 2 < 3 **, 2 < 4 ***, 3 < 4 * 2 < 4 ***, 3 < 4 *		2 > 1 ***, 2 > 3 **, 2 > 4 ***, 3 > 4 *			

Table 3. *Cont.*

Item		*N*	Compassion Satisfaction (CS)		Burnout (BO)		Secondary Trauma (ST) (STS)	
			M	*SD*	*M*	*SD*	*M*	*SD*
Education background	1	220	37.66	7.38	22.95	6.73	25.27	6.13
	2	1219	35.95	7.69	24.59	6.49	25.41	6.33
	3	88	36.52	7.60	24.28	7.00	25.14	5.94
F			4.741		6.240		2.184	
P			0.009		0.003		0.893	
Scheffe			2 < 1 ***		2 > 1 ***			
School type	A	572	37.74	7.32	22.99	6.50	24.43	6.61
	B	599	34.95	7.82	25.56	6.67	26.25	6.09
	C	193	35.44	7.92	24.17	6.25	24.83	5.60
	D	163	36.54	7.08	24.73	5.97	26.10	6.04
F			14.039		15.536		9.540	
P			<0.001		<0.001		<0.001	
Scheffe			B < A ***, C < A **,		B > A ***, D > A *		B > A ***, D > A *	

Note: For teaching age, 1 means 0–3 years, 2 means 4–9 years, 3 means 10–20 years, 4 means more than 20 years; for position, 1 means class teacher, 2 means headteacher, 3 means middle-level school leader, 4 means school-level leaders and above; for title, 1 means unclassified, 2 means primary, 3 means middle, 4 means senior; for education, 1 means college degree or below, 2 means bachelor's degree, 3 means graduate degree or above; for School type, A means primary school, B means secondary school, C means ordinary high school, D means secondary vocational school; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

3.2.1. The Impact of Teaching Experience on CS and BO

One-way ANOVA was used to compare the differences in the dimensions of compassion satisfaction, burnout, and secondary trauma among teachers with teaching experiences of 0–3 years, 4–9 years, 10–20 years, and more. The results showed that in the dimension of compassion satisfaction, $F = 10.383$, $p < 0.001$, a post hoc comparison revealed that teachers with 0–3 years of teaching experience (35.15 ± 7.01) < teachers with more than 20 years of teaching experience (37.66 ± 7.72), teachers with 4–9 years of teaching experience (35.57 ± 7.72) < teachers with more than 20 years of teaching experience (37.66 ± 7.72), teachers with 10–20 years of teaching experience (35.54 ± 7.77) < teachers with more than 20 years of teaching experience (37.66 ± 7.72); in the burnout dimension $F = 6.240$, $p < 0.001$, a post hoc comparison revealed that teachers with 0–3 years of teaching experience (24.85 ± 6.33) > teachers with more than 20 years of teaching experience (23.38 ± 6.51), teachers with 4–9 years of teaching experience (25.06 ± 6.85) > teachers with more than 20 years of teaching experience (23.38 ± 6.51), teachers with 10–20 years of teaching experience (24.79 ± 6.57) > teachers with more than 20 years of teaching experience (23.38 ± 6.51); there were no statistical differences in the secondary trauma dimension among teachers in each teaching experience ($F = 2.184$, $p = 0.088$).

3.2.2. The Impact of the Position of Teacher on CS and BO

A one-way ANOVA was used to compare the differences among classroom teachers, headteachers, middle-level school leaders, and school-level leaders and above on the dimensions of compassion satisfaction, burnout, and secondary trauma, and the results showed that in the compassion satisfaction dimension $F = 21.475$, $p < 0.001$, a post hoc comparison revealed that class teachers (35.58 ± 7.74) < middle-level school leaders (38.80 ± 6.96), class teachers (35.58 ± 7.74) < school-level leaders and above (41.11 ± 7.15), headteachers (35.57 ± 7.39) < middle-level school leaders (38.80 ± 6.96), headteachers (35.57 ± 7.39) < school-level leaders and above (41.11 ± 7.15); in the burnout dimension $F = 16.387$, $p < 0.001$, a post hoc comparison revealed that class teachers (24.78 ± 6.52) > middle-level school leaders (22.51 ± 6.02), class teachers (24.78 ± 6.52) > school-level leaders and above (20.54 ± 6.11), headteachers (24.87 ± 6.62) > middle-level school leaders (22.51 ± 6.02), headteachers (24.87 ± 6.62) > school-level leaders and above (20.54 ± 6.11); teachers in different positions did not differ statistically in the secondary trauma dimension ($F = 1.355$, $p = 0.255$).

3.2.3. The Influence of Teaching Titles on CS and BO

A one-way ANOVA was used to compare the differences in the dimensions of compassion satisfaction, burnout, and secondary trauma among teachers with unclassified, primary, middle, and senior titles, showing that in the dimension of compassion satisfaction $F = 12.120$, $p < 0.001$, a post hoc comparison revealed that teachers with the unclassified title (36.65 ± 6.66) > teachers with the primary title (34.45 ± 8.10), teachers with the primary title (34.45 ± 8.10) < teachers with the middle title (36.26 ± 7.68); in the burnout dimension $F = 16.387$, $p < 0.001$, post hoc comparisons revealed that teachers with the unclassified title (23.57 ± 6.47) < teachers with the primary title (25.85 ± 6.66), teachers with the primary title (25.85 ± 6.66) > teachers with the middle title (24.37 ± 6.61); teachers with different titles did not differ significantly in the secondary trauma dimension ($F = 2.954$, $p = 0.032$).

3.2.4. The Influence of Educational Background on CS and BO

A one-way ANOVA was used to compare the differences in the dimensions of compassion satisfaction, burnout, and secondary trauma among teachers with a college degree or below, a bachelor's degree, and a graduate degree or above, showing that in the compassion satisfaction dimension $F = 4.741$, $p = 0.009$, a post hoc comparison revealed that teachers with a college degree or below (37.66 ± 7.38) > teachers with a bachelor's degree (35.95 ± 7.69); in the burnout dimension $F = 6.240$, $p = 0.003$, and by post hoc comparison, it was found that teachers with a college degree or below (22.95 ± 6.73) < teachers with a bachelor's degree (24.59 ± 6.49); there was no significant difference in the secondary trauma dimension among teachers with different degrees ($F = 2.184$, $p = 0.893$).

3.2.5. The Difference between CS and BO among Different Types of School

A one-way ANOVA was used to compare the differences in the dimensions of compassion satisfaction, burnout, and secondary trauma among primary school, secondary school, ordinary high school, and secondary vocational school teachers. The results showed that in the dimension of compassion satisfaction, $F = 14.039$, $p < 0.001$, a post hoc comparison revealed that primary school teachers (37.74 ± 7.32) > secondary school teachers (34.95 ± 7.82), primary school teachers (37.74 ± 7.32) > ordinary high school teachers (35.44 ± 7.92); in the dimension of burnout, $F = 15.536$, $p < 0.001$, a post hoc comparison revealed that primary school teachers (22.99 ± 6.50) < secondary school teachers (25.56 ± 6.67), primary school teachers (22.99 ± 6.50) < secondary vocational school teachers (24.73 ± 5.97); in the dimension of secondary trauma, $F = 9.540$, $p < 0.001$, a post hoc comparison revealed that primary school teachers (24.43 ± 6.61) < secondary school teachers (26.25 ± 6.09), primary school teachers (24.43 ± 6.61) < secondary vocational school teachers (26.10 ± 6.04).

3.3. The Effect of Demographic Information on Compassion Fatigue

The 1416 primary and secondary school teachers with compassion fatigue were analyzed by using their compassion fatigue degree as the dependent variable and region, gender, teaching experience, teaching subject, position, title, education, location, and school type as explanatory variables in an ordered logistic regression analysis using SPSS25 statistical software. First, all explanatory variables were introduced into a multivariate ordered logistic regression, and the results of the parallelism test were $\chi 2 = 55.885$, $p = 0.108 > 0.05$, indicating that the ordered logistic regression analysis was suitable. Secondly, the insignificant variables in the regression analysis were gradually removed until all the variables entered into the regression analysis were significant. Finally, it was found that teachers' position, title, and the school type had a significant impact on the explanatory variables, and the other explanatory variables were eliminated.

The parallelism test is the basis for determining whether the multivariate ordered logistic regression model is applicable. At this point, the result of the parallelism test was $\chi 2 = 9.415$, $p = 0.400 > 0.05$, which indicates that the ordered logistic regression analysis was still suitable. According to the model fit information-2 log likelihood values of

463.807 and 368.373, respectively, and the likelihood ratio chi-square value of 95.434, $p < 0.001$, the model fit for the three explanatory quantities of position, title, and the type of school they teach was better than the model containing only the constant term. The results of further analysis are shown in Figure 2.

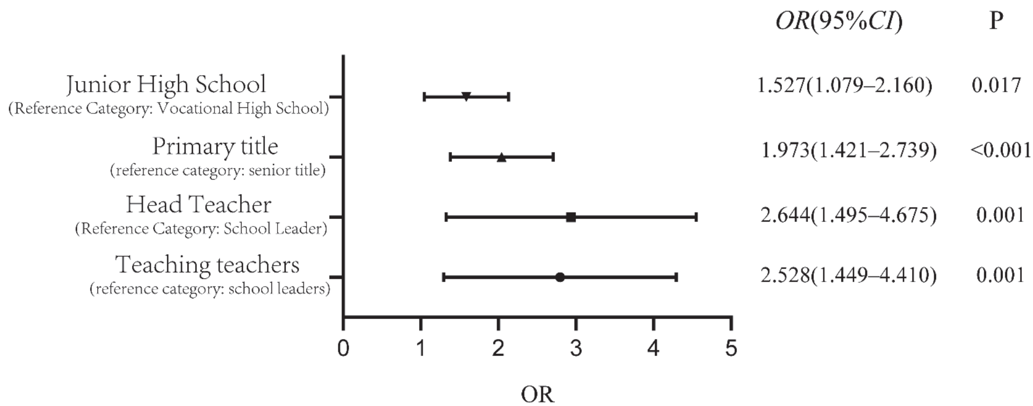

Figure 2. The results of the logistic regression of the influencing factors of compassion fatigue among the primary and secondary school teachers. Logistic regression compares each category to one reference category. The odds ratio (OR) represents the odds that an outcome will occur given a particular exposure, compared to the odds of the outcome occurring in the absence of that exposure. p-value is a statistical measurement used to validate a hypothesis against observed data. The 95% confidence interval (CI) is a range of values that can be 95% confident contains the true mean of the population.

3.3.1. The Impact of Teachers' Position on Compassion Fatigue

Taking leaders at school level and above as the control group, the partial regression coefficients of class teachers and headteachers' job variables were 0.927 and 0.972, respectively, which had a positive impact on the degree of compassion fatigue of primary and secondary school teachers at the 1% statistical level, that is, class teachers and head teachers had a greater impact on the severity of compassion fatigue than leaders at the school level and above. When other conditions remained unchanged, the OR value of compassion fatigue severity of class teachers was 2.528 times higher than that of leaders at the school level and above (95% CI: 1.449–4.410), $\chi 2 = 10.659$, $p = 0.001$. The OR value of compassion fatigue severity of head teachers was 2.644 times higher than that of leaders at the school level and above (95% CI: 1.495–4.675), $\chi 2 = 11.180$, $p = 0.001$.

3.3.2. The Impact of Teachers' Title on Compassion Fatigue

Taking the senior title as the control group, the partial regression coefficients of current primary-title teachers was 0.679, which had a positive impact on the degree of compassion fatigue of primary and secondary school teachers at the 1% statistical level, that is, the primary title had a greater impact on the severity of compassion fatigue than the senior title. When other conditions remained unchanged, the OR value of compassion fatigue severity of primary-title teachers was 1.973 times higher than that of senior-title teachers (95% CI: 1.421–2.739), $\chi 2 = 16.449$, $p < 0.001$.

3.3.3. The Impact of School Type of Teachers on Compassion Fatigue

Taking secondary vocational school as the control group, the partial regression coefficient of current secondary school teachers was 0423, which had a positive impact on the degree of compassion fatigue of primary and secondary school teachers at the 5% statistical level, that is, secondary school had a greater impact on the severity of compassion fatigue than secondary vocational school. When other conditions remained unchanged, the OR value of compassion fatigue severity of secondary school teachers was 1.527 times higher than that of secondary vocational school teachers (95% CI: 1.079–2.160), $\chi 2 = 5.706$, $p = 0.017$.

4. Discussion

Compassion fatigue is a unique form of teacher burnout, which will affect the physical and mental health of primary and secondary school teachers. When passionate teachers are exhausted due to compassion fatigue, their involvement in education and teaching will be reduced, and they will become indifferent and impatient to students, which will have a bad influence on the school and students, and even lead to moral anomie and resignation of teachers. In this study, 92.73% of primary and secondary school teachers had mild or above compassion fatigue, indicating that the problem of compassion fatigue of primary and secondary school teachers should not be ignored.

4.1. Detection Situation of Compassion Fatigue of Primary and Secondary School Teachers

Education can easily lead teachers to burnout as a unique helping profession with high emotional involvement and workload. Many studies also show that teachers are a high incidence group of job burnout [19,20]. Compared with research on teacher burnout, research findings on teacher compassion fatigue—a specific form of teacher burnout—are limited. However, existing studies have also shown that teachers suffer from high levels of compassion fatigue. For example, Borntrager et al. (2012) conducted the first survey of compassion fatigue among teachers in the northwestern United States [21]. They found that approximately 75% of teachers suffered from high levels of compassion fatigue. In June 2020, a survey of 2113 teachers in Alberta, Canada, Kendrick found that 49.6% of teachers had moderate compassion fatigue or above [10]. In this study, 92.73% of primary and secondary school teachers had mild compassion fatigue and above, and more than 44.33% of primary and secondary school teachers had moderate compassion fatigue and above, which is more consistent with the above findings. This may be related to teachers being exposed to pressure sources for a long time in their work practice. They need to deal with various educational and teaching problems and need to establish and maintain a good teacher–student relationship and take the initiative to care for and help students more. Therefore, teachers are prone to compassion fatigue.

4.2. Differences in Dimensions of Compassion Fatigue of Primary and Secondary School Teachers

The statistical analysis found that there are significant differences in compassion satisfaction between teachers in the eastern and mid-western regions, and there are significant differences in secondary trauma. This may be related to the relatively developed economy and extensive investment in education in the eastern region and the relatively high proportion of left-behind children and children with a traumatic experience in the western region. In the dimensions of compassion satisfaction and burnout, there are significant differences among teachers with different teaching experiences, positions, titles, and educational backgrounds, and there are differences among teachers in different school types in the three dimensions of compassion fatigue.

First, from the perspective of teaching experience, teachers with more than 20 years of teaching experience had a significantly higher compassion satisfaction than teachers with 0–3, 4–9, and 10–20 years of teaching experience, and teachers in the other three age groups did not have statistically significant differences in their compassion satisfaction from each other. Education is a career with a long return cycle, and primary and secondary school teachers with more than 20 years of teaching experience are likely to gain a high sense of personal achievement. On the one hand, with the continuous enrichment of their work experience, they obtain richer educational resources and develop professional skills to a higher level; on the other hand, it is also possible that teachers in this age group are already in a stable stage in various aspects such as family, and can receive more social support and a higher sense of satisfaction. The burnout scores of teachers with more than 20 years of teaching experience are significantly lower than those of the other three teaching experience groups, and teachers with 4–9 years of teaching experience have the highest scores in this dimension. This may be because most of the teachers in this age group have adapted to the teaching work, but they are also getting married and having children. The double pressure of family and career makes them exhausted and burned out.

Secondly, from the perspective of position, class teachers and headteachers had significantly lower compassion satisfaction and significantly higher burnout scores than middle-level school leaders and school levels and above. This may be related to the fact that they spend more time in direct contact with students, need to spend more energy on relationships with students, and are under pressure to improve student performance [22].

Thirdly, from the perspective of title, in the compassion satisfaction dimension, teachers with the primary title scored significantly lower than teachers with unclassified, middle, and senior titles, and teachers with the middle title scored lower than teachers with the senior title; in the burnout dimension, teachers with the primary title scored significantly higher than teachers with unclassified, middle, and senior titles, and teachers with the intermediate title scored higher than teachers with the senior title. In China, title affects teachers' sense of self-achievement to a certain extent and is related to their career development, remuneration, and professional status. Generally, the higher the title of a teacher, the higher the treatment and the more respect they can receive. The shortage of middle and senior posts is the most apparent contradiction in evaluating and recruiting titles of primary and secondary school teachers. For unclassified teachers, the junior title is a natural promotion process for most teachers, so there is little pressure on promoting the title. However, the middle title is now close to saturation in many schools. For teachers with the primary title, the promotion of the middle title is a necessary part of their career, but due to factors such as uneven distribution of teacher title positions in various schools, many teachers with the primary title have to pay more for the promotion to the middle title. Hence, their compassion satisfaction is lower, and burnout is higher. Teachers with the middle title have the desire to be promoted to the senior title but have certain expectations about the difficulty of evaluation, so the score difference of compassion satisfaction and burnout dimension is not as significant as that of teachers with the primary title.

Fourthly, from the perspective of educational background, the compassion satisfaction of teachers with a college degree and below is significantly higher than that of teachers with a bachelor's degree and graduate degree and above, and the burnout score is significantly lower than that of teachers with a bachelor's degree and graduate degree and above. This may be because teachers with a college degree or below are mainly distributed in primary schools, and primary schools have relatively no pressure to enter a higher school. It is relatively simple to deal with the teacher–student relationships with primary school students. It is also more accessible for primary school teachers to feel a positive response to their care for students. This is also consistent with the different situations of compassion fatigue among teachers in different types of schools.

Fifthly, from the perspective of school type, the compassion satisfaction of primary school teachers is significantly higher than that of secondary school and ordinary high school, which may be related to the high status of primary school teachers in the eyes of students. Relatively speaking, primary school students respect their teachers more and can better complete the tasks required by teachers, so primary school teachers can receive a better sense of satisfaction. In the compassion fatigue section, secondary school teachers scored higher than primary school teachers at the 1% significant level, and secondary vocational school teachers scored higher than primary school teachers at the 5% significant level. This may be related to the fact that secondary school teachers should not only establish a good teacher–student relationship with adolescent students but also face the pressure of high school entrance examination; among secondary vocational teachers, the proportion of nonnormal graduates is higher, they lack coping skills in student education and management, and the management of secondary vocational students is relatively complicated, which also quickly leads to their compassion fatigue.

4.3. The Influence of Group Types on Teachers' Compassion Fatigue Levels

According to the ordered logistic regression analysis of the level of compassion fatigue of primary and secondary school teachers, the position, title, and the type of school they teach have predictive effects on the compassion fatigue degree of teachers. Headteachers and class teachers spend the longest time directly facing and communicating with students, especially when they need to face and care for students with traumatic experiences, which may mean that these teachers are more likely to experience or elevate the degree of compassion fatigue. Compared to teachers with the senior title, teachers with the primary title need to face the pressure of evaluating and hiring the middle title, while teachers with the primary title generally have 3 years of teaching experience; for young people who graduate from colleges and universities to become teachers, this is also a time when they are ready to get married and have children. Therefore, they will face the dual pressure of personal life and career development and will likely develop compassion fatigue. The secondary school teacher community is one group that needs the most attention. They are under pressure to select students for the high school entrance examination, but secondary school students in adolescence are generally more challenging to manage than primary and high school students. The development of compassion fatigue not only affects the physical and psychological conditions of teachers themselves, with teachers as a participant in the teacher–student relationship, students may also be negatively affected when teachers experience burnout and compassion fatigue, especially for secondary school students in the critical period of physical and mental development [23]. Therefore, there is a greater need for secondary schools to take steps to make teachers aware of compassion fatigue and its consequences and carry out prevention and intervention.

4.4. Merits and Limitations in the Current Study

This study examined the current status of Chinese teachers' compassion fatigue and differences in demographic factors. The current study has some merits and limitations. First, compassion fatigue is a unique mental health issue that can occur after helping people by empathizing, caring, and helping others. In the helping profession, compassion fatigue as a particular kind of burnout is the price of caring. Teachers are exposed to stressors for long periods of time in their work practices, not only to deal with various educational and teaching issues but also to establish and maintain good teacher–student relationships and take the initiative to give more care and help to students, so they are prone to the problem of compassion fatigue, which leads to inappropriate teacher behaviors and affects the professional ethics of teachers. Yet, this issue has not yet attracted attention in China. The current study mainly explored the current situation of Chinese primary and secondary school teachers' compassion fatigue and the influence of demographic factors on compassion fatigue. Subsequent studies can further explore the factors affecting primary and secondary school teachers' compassion fatigue, study the influencing factors of teachers' compassion fatigue in depth, and propose targeted coping strategies to provide data for international research on compassion fatigue.

Second, this study used the Chinese version of the ProQOL-5 scale to conduct the first questionnaire survey on the current situation of compassion fatigue among 1558 primary and secondary school teachers in 28 provincial-level administrative regions in China, which provides a comprehensive understanding of the current situation of compassion fatigue among primary and secondary school teachers in China. The study not only focused on the effects of individual factors and group types on the degree of compassion fatigue among primary and secondary school teachers, but also on the differences in compassion fatigue among teachers in the eastern and western regions of China, trying to understand the differences in the occurrence of compassion fatigue among teachers in regions with different economic levels, educational inputs, and family parenting styles. This is of great importance to enrich the current international research findings on teacher compassion fatigue and to prevent teachers' professional ethical failures due to compassion fatigue. However, it is worth noting that although the sample size of the current study is widely distributed, there are large differences in the number of investigators. Although the overall sample size in the eastern, central, and western regions is not very different, the sample size in some provinces is still relatively small, and the study could be more optimized if some samples were added in these provinces.

5. Conclusions

This study examined the current status of Chinese teachers' compassion fatigue and differences in demographic factors through a research study involving 28 provinces, cities, autonomous regions, and municipalities directly under the central government in the eastern, central, and western regions of China. The findings revealed that Chinese primary and secondary school teachers had an intermediate quality of professional life and generally experienced more than mild compassion fatigue; individual differences in teachers' levels of empathy satisfaction and burnout existed. The findings of this study suggest that education authorities or school administrators should pay more attention to teachers' compassion fatigue while paying attention to primary and secondary school teachers' burnout, help teachers recognize compassion fatigue and improve controllable adverse environmental factors; and actively carry out prevention and interventions for primary and secondary school teachers' compassion fatigue. At the same time, teachers need to clarify the boundaries of their professional competence: teachers need to take responsibility for their profession, but not all of it.

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Article

The Development and Evolution of Digital Leadership: A Bibliometric Mapping Approach-Based Study

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Abstract: The inevitable digitalization of workplaces in the present era, generally as a result of technological developments, has caused a paradigm shift, along with new innovative business models and business behaviors, which has required leaders to possess certain digital skills for sustainable corporate performance. Hence, studies on digital leadership have attracted the attention of academics and practitioners worldwide, with many studies having been conducted on the topic. However, a comprehensive analysis of the intellectual architecture, knowledge structure, and thematic evolution of the digital leadership field of research using science mapping tools has yet to be conducted. The current study, therefore, aimed at reviewing the intellectual structure and evolution of the digital leadership field through a bibliometric and science-mapping analysis. This study used digital leadership as *an umbrella term* comprising leadership styles such as *e-leadership*, *virtual leadership*, *technology leadership*, and *leadership 4.0*, which have similar meanings and can be used interchangeably. With this purpose, bibliometric performance and science mapping analysis was performed on articles related to the research field that were retrieved from the Scopus database using SciMAT software (version 1.1.04). The results of the study revealed that the scope of digital leadership research is gradually expanding and diversifying and that publication output is increasing steadily. In addition, period-based analysis showed that the *technology management* theme during the first period, the *virtual teams* and *technology* themes during the second period, and the *COVID-19, virtual reality,* and *digital technologies* themes during the third period emerged as the motor themes and formed the focus of research in this field. Thematic evolution analysis showed that *virtual leadership* during the first and second periods, *virtual teams* during the second period, *e-leadership* and *technology* during the second and third periods, and *digital leadership*, *COVID-19,* and *virtual reality* during the third period, along with *technology leadership* in all three periods were all noteworthy as well-developed research themes. These findings enable a better understanding of the research field of digital leadership and provide a reference for future research by revealing the conceptual structure and thematic evolution of the digital leadership knowledge base.

Keywords: digital leadership; technology leadership; e-leadership; virtual leadership; leadership 4.0; bibliometric analysis; science mapping; SciMAT

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1. Introduction

Developments in the digital age have encouraged digitalization in every field, triggering various changes across almost all sectors [1] and forcing organizations of different sizes and from various sectors to transform themselves into digital workspaces [2]. Even in institutions with lower levels of digitalization, employees now have generally prolonged contact with their workplaces via mobile devices and applications, with more and more people working through virtual teams, and information is being shared via digital platforms [3]. Therefore, the digital age requires leaders in many organizations worldwide to combine traditional leadership skills with digital skills [1].

Digital leadership is a new leadership style associated with industry 4.0 [4]. The first three industrial revolutions consisted of mechanical production (mechanization), electricity, and information technologies, respectively. The fourth industrial revolution, which has seen new business models created, relates to the introduction of the internet of things into production, as well as human-to-device and device-to-device communication [5,6]. The development of industry 4.0, which is considered to be a technology-themed project and a new style of production, has not only led to the emergence of digital leadership [7–9], but has also become significant in the initiation of digitalization and digital transformation. Digitalization has changed the way many organizations operate; however, organizations never transform by themselves. The most important factor that enables such technological transformation or change within an organization is the vision of its leaders regarding digitalization [10].

Digital transformation emphasizes the economic and social effects of digitalization, while digitization refers to the conversion of analog data and processes into a format that is machine-readable [11]. Digital transformation is characterized by the integration of physical and digital systems through combining advanced technologies, as well as creating innovative business models and smart products/services [12]. Based on this perspective, digital transformation has become important for organizations across all sectors as it impacts stakeholder relations, work procedures, and even value creation processes. The main concern of stakeholders in this transformation is to define a vision and roadmap that reflects a viable way forward [13]. The aim of digital transformation is to provide continuous optimization to an organization's capability to detect and quickly respond to changes in the global world [14]. In the present era, it is believed that organizations that cannot catch up with the current digitalization trend will become slower, less flexible, and, therefore, less competitive than digitally pioneering organizations [15].

2. Literature Review

The world has always been in a state of change and transformation, but the most striking difference between the changes seen in the past and that of today is the sheer speed and extent of the changes taking place. Innovations in information technology, along with globalization, digitalization, and communication technologies, have caused many organizations to radically change their management processes. The use of information technology began in the 1970s with the first computer systems used in industry. However, since then, the use of information technologies and digitalization have been of crucial importance for industry, public administration, and society as a whole [16].

Digital technology is undoubtedly the trigger of the rapid changes we are experiencing in today's industrial and social world. Broadband internet access, mobile smart devices, artificial intelligence, virtual reality, and many other technology-based applications have taken place in all areas of modern-day life. In this regard, leaders who can effectively manage the digital world can also make a meaningful contribution to the digital transformation of their organizations [17]. Leaders are of critical importance to organizations with their role of selecting, equipping, training, and influencing personnel (employees) [18]. Therefore, it is important for leaders to support and motivate employees so as to improve their digital skills in the rapidly developing digital environment of the current age, in which radical transformation is brought about through digitalization [2]. Constantly changing and developing business environments, taken together with the human factor, have led to the emergence of different leadership styles. New digital tools that emerged with the development of internet technologies have become a vital element for leaders with the digitalization of workplaces [19,20]. In this context, both the industry 4.0 revolution and the developments seen in internet technologies have required leaders to possess certain digital competencies, which has paved the way for the emergence of digital leadership. In addition, the need for digital leadership has increased more than ever before since today's organizations have transformed or are in the process of transforming from traditional to digital workplaces [21].

In the relevant current academic literature, digital leadership is defined as a leadership style that combines transformational leadership with the use of digital technologies [22,23]. Avolio et al. [24] used the term e-leadership, a term that combines leadership and technology. Within the scope of the current study, digital leadership is used as an *umbrella term* that comprises leadership styles such as *technology leadership*, *virtual leadership*, *e-leadership*, and *leadership 4.0.*, all of which share a similar meaning and are used interchangeably throughout the literature.

Digital leadership is described as a social influence process mediated by modern information technologies to support change and the improvement of behaviors and organizational performance across all stakeholder groups. From this perspective, digital leaders aim to consistently manage digital transformation processes by adopting multiple leadership approaches. Therefore, effective digital leadership requires an empathetic problem-solving perspective, fast, accurate, and participatory decision-making ability, as well as effective networking skills [24–26]. In addition, Promsri [27] underlined the different qualities of digital leadership such as digital literacy, vision, customer focus, agility, risk taking, and cooperation.

The results of a study by Karakose et al. [23] showed that the basic qualities of digital leaders include (i) the use of digital technology, (ii) support for digital transformation, (iii) support for technology-based professional development, (iv) support for a digital learning culture, and (v) digital leadership skills (technology use, managerial skills, and individual skills). In this sense, digital leadership is not about bringing computers together, running them, or being an expert programmer. Digital leaders are visionary people who have the ability to effectively lead an organization by using information and communication technologies in order to meet the demands of the digital age [28]. According to Miller [29], digital leaders can improve the life, well-being, and conditions of an organization and its employees by using a wide array of digital technologies.

In times of crisis, leaders may need to take on different roles in order to overcome certain challenges. On 11 March 2020, the World Health Organization declared COVID-19 as a pandemic [30] that resulted in a period of significant chaos and crisis for leaders, organizations, and employees worldwide. When considered in terms of educational management, it may be said that COVID-19 created a clear need for social distancing, which resulted in the almost overnight transformation of predominantly traditional learning systems into digital active areas [31]. The business world, on the other hand, also had to change its business models from the outset of the pandemic in order to adapt to new digital conditions that triggered a period of rapid change and development [32]. These challenging processes rendered the digital capabilities of leaders even more significant, and research interest in digital leadership was seen to increase during the pandemic [33,34].

In the digital age, the effective and sustainable success of organizations depends heavily on traditional leaders who can support their leadership with digital skills. In recent years, digital leadership has garnered significant research interest, and numerous studies have been carried out on digital leadership in different research fields, such as the social sciences [35], engineering [36], business and management [37], economics [38], and health [39]. However, to our knowledge, the literature lacks a conceptual analysis based on bibliometric methods and science mapping tools that comprehensively investigate the evolving field of digital leadership. Therefore, this research aims to reveal the intellectual structure and evolution of the digital leadership knowledge base using bibliometrics and science mapping methods. More specifically, our study addresses the following research questions:

RQ 1. What is the overall volume, growth trajectory, and distribution of published articles in the digital leadership knowledge base?
RQ 2. What are the most influential authors and journals in the digital leadership research field?
RQ 3. What is the intellectual structure and evolution of the digital leadership knowledge base?
RQ 4. What topical foci in digital leadership research have attracted the greatest attention from scholars?

3. Materials and Methods

3.1. Study Design

In this study, we combined bibliometric performance analysis and science mapping methods to determine the strategic themes, scientific evolution structure, and bibliometric performance of articles on digital leadership. We used SciMAT [40] software (version 1.1.04) to analyze the bibliometric performance, the conceptual structure, and the thematic evolution of 314 articles published on digital leadership. SciMAT combines science mapping and bibliometric performance analysis methods to examine the structural and dynamic aspects of a research field, to visualize its thematic evolution, and to determine its performance [41–43].

Comparing SciMAT with other bibliometric analysis tools, such as WOSviewer, Bibexcel CiteSpace II, CoPalRed, or the Science of Science Tool (Sci2), Cobo et al. [43] highlight the salient features of SciMAT as (i) incorporating modules to carry out all the steps of the science mapping, (ii) presenting a powerful deduplicating module, (iii) building a large variety of bibliometric networks, (iv) enabling the use of various visualization techniques, such as cluster or thematic evolution networks, (v) enriching the results with bibliometric measures based on citations, such as the sum, minimum, maximum, and average citations, or complex measures, such as the h-index, and as a result, allows for science mapping analysis under a longitudinal framework to analyze and discover the conceptual and intellectual evolution of a research field across consecutive time periods. Therefore, in light of our purpose, we preferred to use the SciMAT software in the present study.

3.2. Data Search and Identification

Digital databases, such as the Web of Science (WoS), Scopus, or Google Scholar, are often preferred for searching and extracting data in bibliometric studies. Mongeon and Paul-Hus [44] stated that Scopus covers more journals than WoS; however, almost all of the articles indexed in the WoS database are also indexed in Scopus. Therefore, the use of Scopus database helps to prevent data loss by reducing the risk of articles being missed from the analysis. Cañadas et al. [45], on the other hand, emphasized that Scopus is accepted as one of the optimum databases for bibliometrics. It also offers more complete bibliographic data than Google Scholar [46]. Therefore, we used the Scopus database to search and extract data. In this study, a three-step process of searching and defining data, extracting and cleaning data, and finally analyzing data [47] was followed. The procedure for data search and extraction was reported according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidance [48] (see Figure 1).

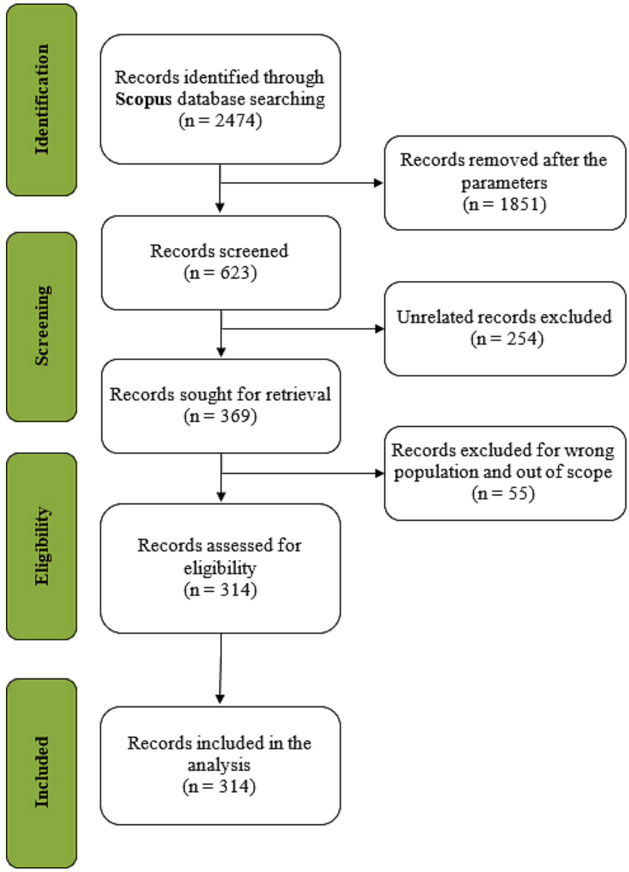


Figure 1. PRISMA flow diagram.

We first developed an inclusion/exclusion criteria list in light of the purpose of our study. The list included four main headings: *language, context, document type,* and *database*. In terms of language, we only included articles written in English due to the authors' ability to understand and analyze English-only content. With regard to context, our search was broad, so we included research in any context as long as it addressed digital leadership or one of its types. However, we included only journal articles while excluding conference proceedings, books, or book chapters. As detailed above, the search was performed using the Scopus database, as it covered a wide variety of journals from various research fields.

Next, we performed a keyword search against the Scopus database on 15 May 2022 using the following keyword string:

> *TITLE-ABS-KEY ("digital leader*" OR "technology leader*" OR "virtual leader*" OR "e-leader*" OR "electronic leadership" OR "4.0 leadership" OR "leadership 4.0" OR "online leadership" OR "remote leadership" OR "cyber leadership").*

Keywords were selected after an in-depth review of the relevant literature and with the approval of a group of field experts. This initial search yielded a total of 2474 documents. After excluding 1851 documents that did not meet the search criteria, 623 articles remained. Then, we examined the titles of these 623 items individually and excluded a further 254 since they were not directly related to the topic of digital leadership. We then read the abstracts of the remaining 369 documents in detail and excluded a further 55 documents as they were not found to be directly focused on digital leadership. The final number of documents eligible for analysis was 314 published articles.

3.3. Data Extraction and Analysis

After performing a data search and identification against the Scopus database, we transferred the bibliographic data of the articles (article title, authors, keywords, abstract, citations, publication date, and journal name) to the SciMAT program for analysis. Next, we manually combined key terms with similar meanings, such as *leader* and *leaders, virtual leader* and *virtual leaders, e-leadership* and *electronic leadership*, etc., in order to increase the efficiency and quality of the thematic analysis. The details of the bibliometric analysis based on the h-index and coword analysis using the SciMAT software tool are as follows [42,43,49–52]:

(a) Within the scope of the current study, we used the *equivalence index* to calculate the similarity of conceptual links between keywords. We used the clustering algorithm, which is a simple central algorithm that shows the relationship strength of clusters to detect themes. At this stage, we prepared to present the *digital leadership* research themes using two different tools, *strategic diagram* and *thematic network*, in a four-quadrant, two-dimensional strategic diagram based on centrality (x-axis) and density (y-axis) values. Here, centrality measures the degree of interaction of a cluster with other clusters or the strength of their relationship, which is formulated as $c = 10 \times \Sigma ekh$. Density, on the other hand, measures the internal strength of the link, that is, the strength of the relationship between the keywords within a theme, which is formulated as $d = 100(\Sigma eij/w)$.

(b) However, for a conceptual analysis based on coword and h-index analysis, the research themes were divided into four categories, as shown in the *strategic diagram* in Figure 2a: *(a) Motor themes (Q1)*: high centrality and intensity (themes are well-developed and considered important to the research field); *(b) Basic and transversal themes (Q2):* high centrality and low density (themes not well-developed due to a lack of appropriate density, but have potential to evolve into motor themes in the future due to high centrality); *(c) Emerging or declining themes (Q3):* low centrality and density (themes not well-developed and represent the field's marginal topics); and *(d) Highly developed and isolated themes (Q4):* low centrality and high density (themes with good density but poor centrality, representing topics that lack the appropriate background for the field).

(c) *Thematic network structure.* Figure 2b shows how strategic themes emerge together with other subthemes related to the research field. The size of the circles in the thematic networks relates to the number of publications, whilst line thickness relates to the relationship strength. The *thematic evolution map* (see Figure 2c) helps to explore the original themes, as well as their evolution and interrelationships over time. Solid lines on the thematic map indicate that the same keywords are shared between themes, whilst the dashed lines indicate that common words are shared apart from the theme names. The line thickness relates to the degree of relationship, whilst the circle size relates to the number of publications.

In order to save the data from uniformity [43,53], we performed the analysis over consecutive periods. We first divided the articles on digital leadership into three distinct time periods: 1983–2007 as Period 1, 2008–2014 as Period 2, and 2015–2021 as Period 3. As the criterion for determining the periods, we took the production of the relevant literature (i.e., the number of publications) as a basis. However, since the current research was performed in 2022, we excluded articles published during 2022 from the science mapping analysis since the year was ongoing at the time.

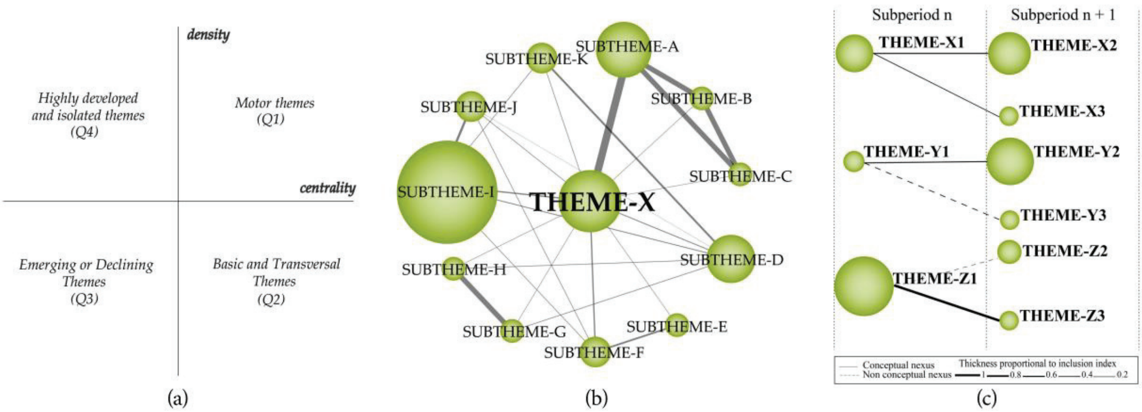


Figure 2. (**a**) Strategic diagram, (**b**) thematic network structure, (**c**) thematic evolution structure [43].

4. Results

4.1. Overall Bibliometric Analysis

In this section, we performed an analysis based on bibliometric indicators in order to evaluate the *digital leadership* research field in light of the quantitative data.

4.1.1. Publication Trends

Figure 3 shows the distribution of 314 digital leadership-focused articles by year of publication, the number of accumulated publications, and the graphical representation of the average citations per article [53]. The continuous red line in Figure 3 shows the yearly citation rates, whilst the continuous grey line shows the number of articles accumulated per year, and the green columns denote the distribution of articles by year of publication.

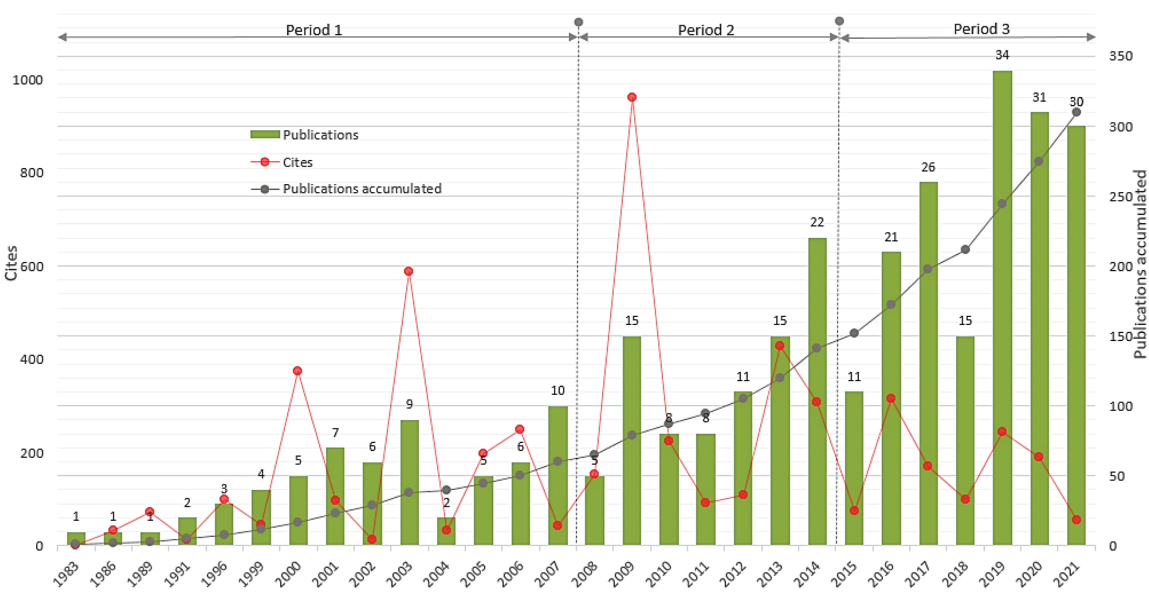


Figure 3. Chronological distribution of publications and citations (1983–2021).

Figure 3 illustrates that studies on digital leadership increased each year cumulatively, starting from 1983, although the annual increase in the number of publications fluctuated on a period-by-period basis. The highest citation year for articles on digital leadership was 2009. In Period 3 (2015–2021), the number of publications on digital leadership increased more extensively, which reveals that research interest in digital leadership reached a peak during the last period. In addition, despite the significant increase in the number of publications on digital leadership during the third period, the articles published during this time received fewer citations compared to publications in previous periods.

4.1.2. Most Influential Authors

The authors of 314 articles were analyzed, and the total number of contributors was determined as 629, although some authors were involved in more than one study. Table 1 presents the top 20 authors who contributed the most to the literature on digital leadership based on the total number of citations their articles received. The names of the authors, the number of cited articles, their h-index value, and the number of citations are presented, respectively, in Table 1.

Table 1. Most cited/productive authors.

Rank	Author	TC *	TP	h-Index
1	Wang, Xiaofan	1065	9	47
2	Su, Housheng	1016	4	45
3	Lin, Zongli	760	1	62
4	Avolio, Bruce J.	597	3	78
5	Dodge, George E.	307	1	4
6	Kahai, Surinder Singh	457	3	22
7	Chu, Tianguang	216	2	31
8	Shi, Hong	216	2	11
9	Wang, Long	216	2	81
10	Lu, Xiaoqing	209	3	22
11	Cascio, Wayne F.	186	1	34
12	Chen, Shihua	186	2	28
13	Shurygailo, Stan	186	1	2
14	Dexter, Sara	171	2	13
15	Anderson, Ronald E.	170	1	13
16	Baker, Bradford	140	1	3
17	Sosik, John J.	140	1	39
18	Lü, Jinhu	138	1	69
19	Lu, Renquan	138	1	57
20	Bader, Paige	136	1	1

* TC: total citations; TP: total publications. Data retrieved from Scopus on 15 May 2022.

According to the 314 analyzed articles, the most cited authors on digital leadership were found to be Wang, X. (f = 1065) and Su, H. (f = 1016), with Wang, X. having made the highest contribution to the field, with nine articles and an h-index value of 47.

4.1.3. Most Influential Journals

Between 1983 and 2021, a total of 314 articles were published on digital leadership in 245 different journals. The top 20 journals are listed in Table 2 based on the total number of published articles, with their respective Scimago Journal Rank (SJR) and Scopus Quartile value.

Table 2. Most productive/cited journals.

Rank	Journal Name	TP *	TC	SJR	Scopus Quartile
1	Research Technology Management	6	43	0.90	Q1
2	British Journal of Educational Technology	5	116	1.87	Q1
3	Organizational Dynamics	4	477	0.49	Q2
4	Egitim ve Bilim	4	38	0.24	Q3
5	Turkish Online Journal of Educational Technology	4	17	n/a	n/a
6	MIT Sloan Management Review	3	93	0.65	Q2
7	International Journal of Environmental Research and Public Health	3	30	0.81	Q1
8	Management Science Letters	3	29	n/a	n/a
9	TechTrends	3	13	0.74	Q1
10	International Journal of Learning, Teaching and Educational Research	3	11	0.23	Q3
11	ITNOW	3	2	0.12	Q4
12	Leadership Quarterly	2	447	4.91	Q1
13	Educational Administration Quarterly	2	185	1.95	Q1
14	Journal of Educational Administration	2	118	1.01	Q1
15	MIS Quarterly Executive	2	108	2.00	Q1
16	Journal of Information Technology For Teacher Education	2	49	n/a	n/a
17	Educational Technology and Society	2	47	1.31	Q1
18	Frontiers in Psychology	2	47	0.87	Q1
19	Computers and Education	2	39	3.68	Q1
20	Sustainability (Switzerland)	2	22	0.66	Q1

* TP: total publications; TC: total citations; SJR: Scientific Journal Ranking. Data retrieved from Scopus on 15 May 2022.

Table 2 shows that the journals with the highest number of articles published on digital leadership were *Research Technology Management* (f = 6), the *British Journal of Educational Technology* (f = 5), and *Organizational Dynamics* (f = 4), respectively. When the Scopus Quartile values of the journals are observed, it can be seen that 12 journals are included in the Q1 category, whilst two journals are included in the Q2 category, and these journals have a significant number of citations.

4.2. Science Mapping and Performance Analysis

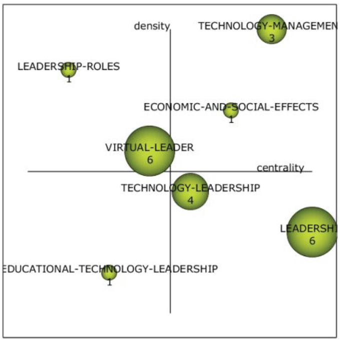
In this section, the results of the science mapping analysis using the SciMAT software are reported as (i) thematic analysis, according to periods (strategic diagrams and thematic networks), (ii) overlapping graph analysis, and (iii) evolution map analysis. In addition, the performance analysis of the themes is presented separately in terms of the h-index value, the number of citations, and the centrality and intensity values.

4.2.1. Scientific Evolution Structure

Period 1 (1983–2007)

Seven themes emerged from the analysis of the 62 articles published during the first period. The performance values of the first period and the strategic diagram are presented in Figure 4.

(a) Period 1 (1983–2007)	(b) Themes Performance



Theme	h-index	Cites	Centrality Range	Density Range
TECHNOLOGY-MANAGEMENT	3	30	0.86	1
ECONOMIC-AND-SOCIAL-EFFECTS	1	22	0.71	0.71
LEADERSHIP	6	327	1	0.29
TECHNOLOGY-LEADERSHIP	4	294	0.57	0.43
VIRTUAL-LEADER	6	1190	0.43	0.57
EDUCATIONAL-TECHNOLOGY-LEADERSHIP	1	38	0.29	0.14
LEADERSHIP-ROLES	1	15	0.14	0.86

Figure 4. (**a**) Strategic diagram for Period 1 and (**b**) performance analysis for Period 1. Source: SciMAT.

During the first period (1983–2007), a total of seven main themes emerged. The *Technology-Management* and *Economic-And-Social-Effects* themes were found to be the motor themes that contributed the most to the development of the field. The *Leadership-Roles* and *Virtual-Leader* themes were found to be highly developed and isolated themes. The *Educational-Technology-Leadership* theme was an emerging and declining theme, which first emerged and then disappeared during the first period. The *Leadership* and *Technology-Leadership* themes were included in the basic and transversal themes, which shows that these themes, despite being related to the field, were not developed sufficiently during the first period. The theme with the highest importance during the first period was the *Virtual-Leader* theme, which is represented by eight articles.

The cluster networks (see Figure 5) were examined in order to determine the subthemes related to the main themes that emerged during the first period (1983–2007). Accordingly, it was determined that the main theme of *Technology-Management* (0.86, 1) was associated with the *Strategic-Leadership, Leadership-Qualities, Industry, Management-Science, Manager, Industrial-Management, Teaching,* and *Product-Development* subthemes. Strong relationships were observed between these subthemes. Studies on *Industry* [54], *Leadership Qualities* [55], *Strategic Leadership* [56], *Manager* [57], *Product Development* [58], *Teaching* [59], and *Management Science* [60] support our results with regards to the *Technology-Management* cluster network.

The analysis also revealed that the main theme of Economic-And-Social-Effects (0.71, 0.71) had associations with the Technology-Transfer, Labor-Market, Engineering, Marketing, and Computer-Science subthemes. Studies on Engineering [61], Computer-Science [62], and Market [63] are offered as examples to support our results with regard to the Economic-And-Social-Effects cluster network.

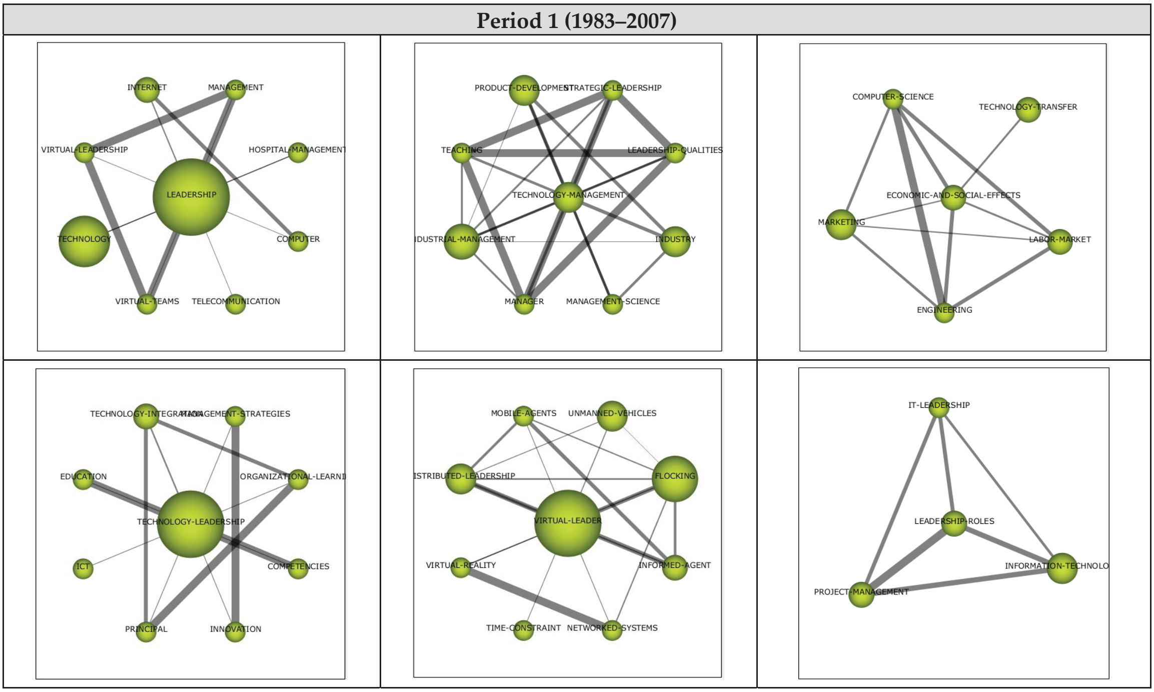
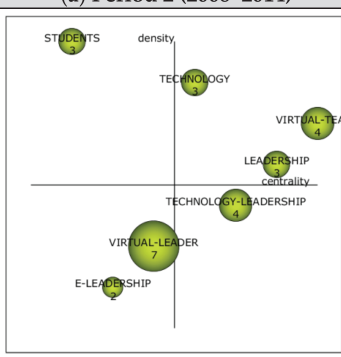


Figure 5. Thematic network structures (1983–2007).

Period 2 (2008–2014)

A total of seven themes emerged from the analysis of the 84 articles published during the second period. The performance values and strategic diagram of Period 2 are presented in Figure 6.

(a) Period 2 (2008–2014)



(b) Themes Performance

Theme	h-index	Cites	Centrality Range	Density Range
VIRTUAL-TEAMS	4	65	1	0.71
LEADERSHIP	3	22	0.86	0.57
TECHNOLOGY-LEADERSHIP	4	53	0.71	0.43
TECHNOLOGY	3	39	0.57	0.86
VIRTUAL-LEADER	7	339	0.43	0.29
E-LEADERSHIP	2	140	0.29	0.14
STUDENTS	3	57	0.14	1

Figure 6. (**a**) Strategic diagram for Period 2 and (**b**) performance analysis for Period 2. Source: SciMAT.

The most significant theme that emerged during the second period (2008–2014) was found to be *Virtual-Leader*, represented by 12 articles. The *Virtual-Teams*, *Leadership*, and *Technology* themes emerged as the motor themes that contributed the most to the development of the field, whilst the *Students* theme was found to be highly developed and isolated. The *Virtual-Leader* and *E-Leadership* themes were shown to be emerging and declining themes during the second period, whereas the *Technology-Leadership* theme, on the other hand, was found to be a basic and transversal theme, indicating that, despite being related to the field, it was underdeveloped during this period.

The cluster networks of the motor themes (see Figure 7) were examined in order to determine the subthemes related to the motor themes that emerged during the second period (2008–2014). Accordingly, the motor theme of *Virtual-Teams* (1, 0.71) was found to be associated with the subthemes of *Web-enabled Leadership*, *Video-Conferencing*, *Communication*, *Virtual-Reality*, *Management*, *Leadership-Roles*, *Emergent-Leadership*, and *Online-Communication*. Studies on *Web-enabled Leadership* [64], *Video Conferencing* [65], *Communication* [66], *Virtual Reality* [67], *Leadership Roles* [68], *Emergent Leadership* [69], and *Online Communication* [70] and are illustrative of the subthemes in the *Virtual-Teams* cluster network.

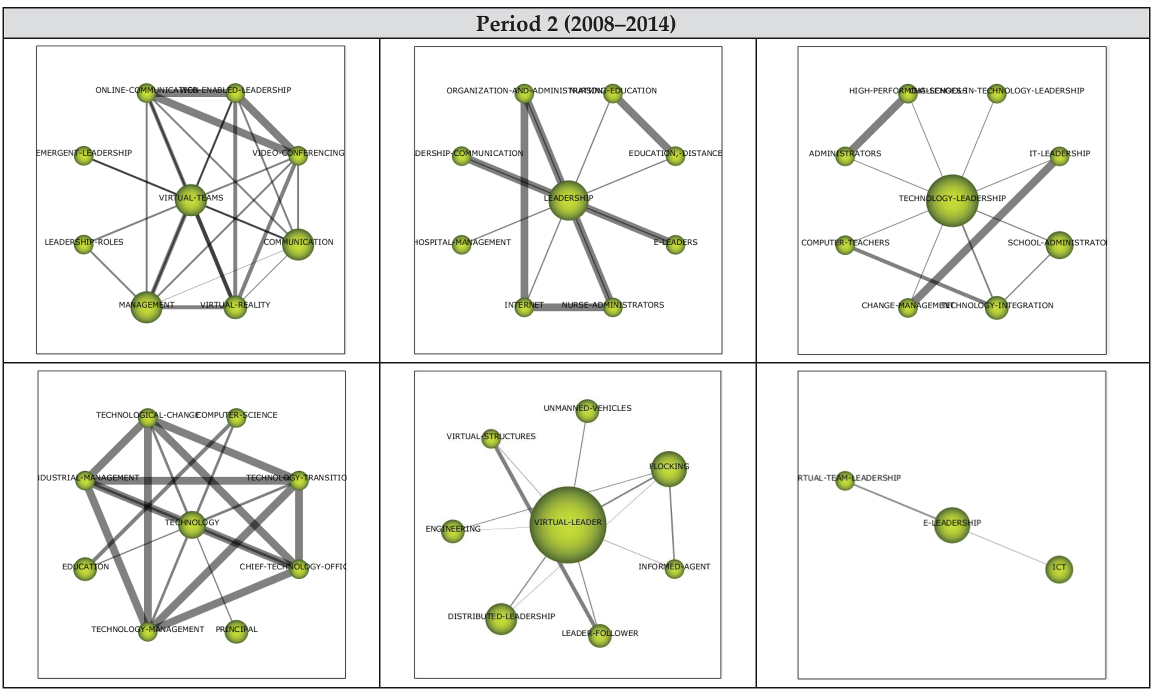


Figure 7. Thematic network structures (2008–2014).

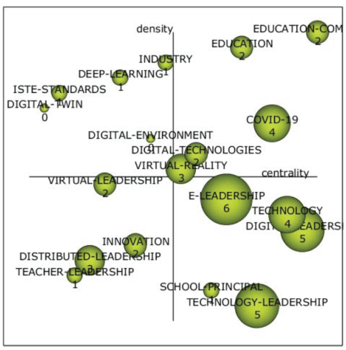
The Leadership (0.86, 0.57) main theme was found to have strong associations with the subthemes of Nursing-Education, Education-Distance, E-Leaders, Nurse-Administration, Hospital-Management, Leadership-Communication, and Organization-And-Administration. Studies on Nursing education [71], E-Leaders [72], Nurse Administrator [73], Hospital Management [74], and Leadership Communication [70], which are examples supporting the subthemes revealed for the Leadership cluster network.

In addition, the main theme of Technology was found to be strongly associated with the subthemes of Computer-Science, Technology-Transition, Chief-Technology-Officer, Principal, Technology-Management, Education, Industrial-Management, and Technological-Change. Studies by van der Hoven et al. [75] on Technology Transition and Chief Technology Officer, Weng and Tang [76] on Principal, Aksal [77] on Technology Management, and Jameson [78] on Education are some of the studies that illustrate the subthemes of the Technology cluster network.

Period 3 (2015–2021)

A total of 19 themes emerged from the analysis of the 168 articles published during the third period. The performance values and strategic diagram of the themes in Period 3 are presented in Figure 8.

(**a**) **Period 3 (2015–2021)**



(**b**) **Themes Performance**

Theme	h-index	Cites	Centrality Range	Density Range
EDUCATION-COMPUTING	2	22	1	1
DIGITAL-LEADERSHIP	5	105	0.95	0.32
TECHNOLOGY	4	51	0.89	0.37
COVID-19	4	73	0.84	0.68
TECHNOLOGY-LEADERSHIP	5	40	0.79	0.05
EDUCATION	2	10	0.74	0.95
E-LEADERSHIP	6	133	0.68	0.42
SCHOOL-PRINCIPAL	1	16	0.63	0.11
DIGITAL-TECHNOLOGIES	2	95	0.58	0.58
VIRTUAL-REALITY	3	13	0.53	0.53
INDUSTRY	1	1	0.47	0.89
DIGITAL-ENVIRONMENT	0	0	0.42	0.63
INNOVATION	2	18	0.37	0.26
DEEP-LEARNING	1	43	0.32	0.84
VIRTUAL-LEADERSHIP	2	14	0.26	0.47
DISTRIBUTED-LEADERSHIP	3	27	0.21	0.21
TEACHER-LEADERSHIP	1	11	0.16	0.16
ISTE-STANDARDS	1	2	0.11	0.79
DIGITAL-TWIN	0	0	0.05	0.74

Figure 8. (**a**) Strategic diagram for Period 3 and (**b**) performance analysis for Period 3. Source: SciMAT.

During the third period, which comprised the years between 2015 and 2021, 19 main themes emerged. The *Digital-Leadership* theme emerged as the most significant theme, represented by 18 articles. The motor themes that contributed to the development of this research field during the third period were found to be *Education-Computing, COVID-19, Education, Digital-Technologies*, and *Virtual-Reality*, whilst the *Industry, Deep-Learning, ISTE-Standards, Digital-Twin*, and *Digital-Environment* themes emerged as highly developed and isolated themes with high interrelationships. The *Virtual-Leadership, Innovation, Distributed-Leadership*, and *Teacher-Leadership* themes were found to be emerging and declining during this third period, and the *E-Leadership, Digital-Leadership, Technology, Technology-Leadership*, and *School-Principal* themes were among those considered basic and transversal, which were not developed sufficiently during the third period despite being related to the field.

The cluster networks of the motor themes (see Figure 9) that emerged during the third period (2015–2021) were examined in order to determine the associated subthemes. The motor theme of *Education-Computing* (1, 1) was found to be strongly associated with the *Education-Reform, Organizational-Factors, Interactive-Learning-Environment, Learning-Communities, Teaching, Economic-And-Social-Effects, Leadership-Qualities*, and *Risk-Management* subthemes. The studies on *Education Reform* [79], *Organizational Factors* [80], *Interactive Learning Environment* [81], *Learning Communities* [82], *Teaching* [83], and *Leadership Qualities* [81] are representative of the findings with regard to the *Education-Computing* cluster network.

In addition, the motor theme of Education (0.74, 0.95) was found to have strong associations with the Nursing-Management, M-Learning, Nurse-Administrators, Hospital-Management, Information-Processing, Organizational, Virtual, and Mentor subthemes. Studies on Nursing Management [84] and Mentor [85] are offered as support for the results revealed with regards to the Education cluster network.

The motor theme of COVID-19 (0.84, 0.68) was found to have strong associations with the Work-From-Home, K-12-Education, Teleworking, Technology-Capabilities, Learning, Remote-Working, New-Normal, and Leadership-Efficacy themes, whilst Work-From-Home and Leadership-Efficacy were found to be strongly associated with the themes of K-12-

Education, Technology-Capabilities, and Learning. The studies on Work from Home [34], Teleworking [86], Technology Capabilities [23], Remote Working [87], New Normal [88], and Leadership Efficacy [34] illustrate our results with regard to the COVID-19 cluster network.

The motor theme of Digital-Technology (0.58, 0.58) was found to have strong associations with Digital-Innovation, Digital-Technologies, Decision-Making, Leadership-Style, Strategic-Leadership, Digital-Teaching, Business-Organizations, Virtual-And-Augmented-Reality, and Organizational-Change. In addition, the Virtual-And-Augmented-Reality, Strategic-Leadership, and Business-Organizations themes had strong interrelationships. The studies on Digital-Innovation [89], Digital-Technologies [90], Decision-Making [91], Leadership-Style [92], Strategic-Leadership [93], Digital-Teaching [94], and Organizational-Change [95] are supportive of our results with regard to the Digital-Technology cluster network.

The motor theme of Virtual-Reality (0.53, 0.53) was found to be associated with the sub-themes of Unmanned-Vehicles, Flocking, Employee, Group-Process, Virtual-Leader, Workplace, Mobile-Agents, and Leadership-Behavior. In addition, the Leadership-Behavior and Group-Process, and Mobile-Agents and Flocking themes were found to have strong interrelationships. The studies on Flocking and Mobile Agents [96], Workplace [97], Leadership-Behavior [98], and Group-Process [99] are offered as support for the presented results with regard to the Virtual-Reality cluster network.

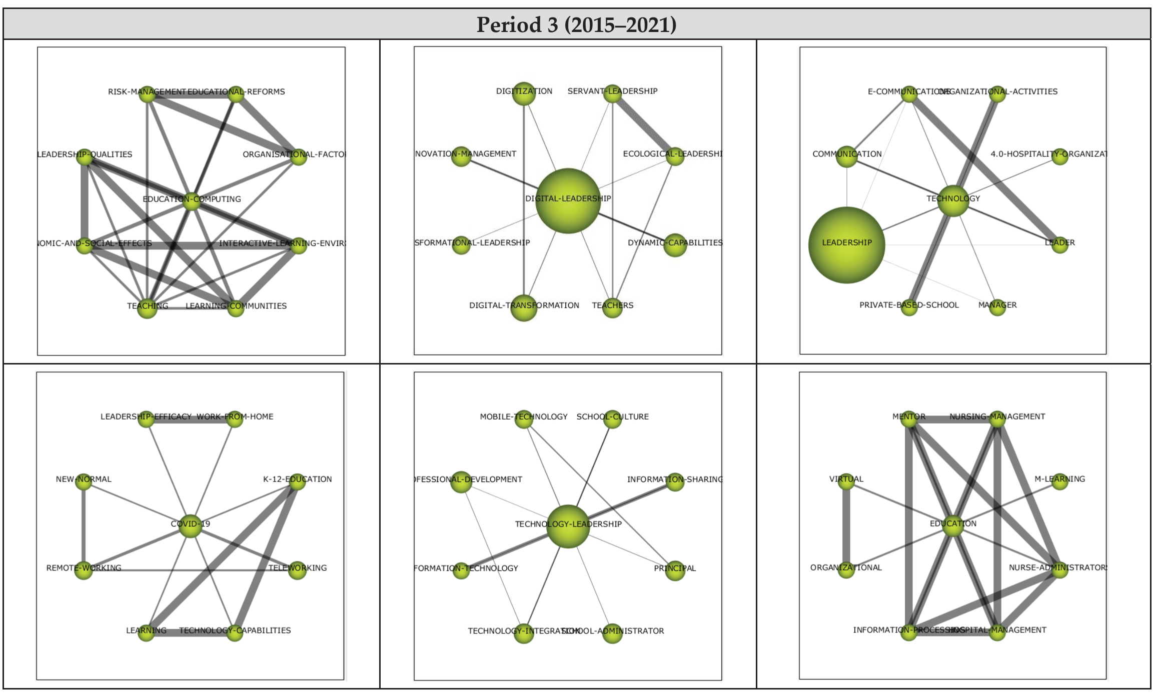


Figure 9. *Cont.*

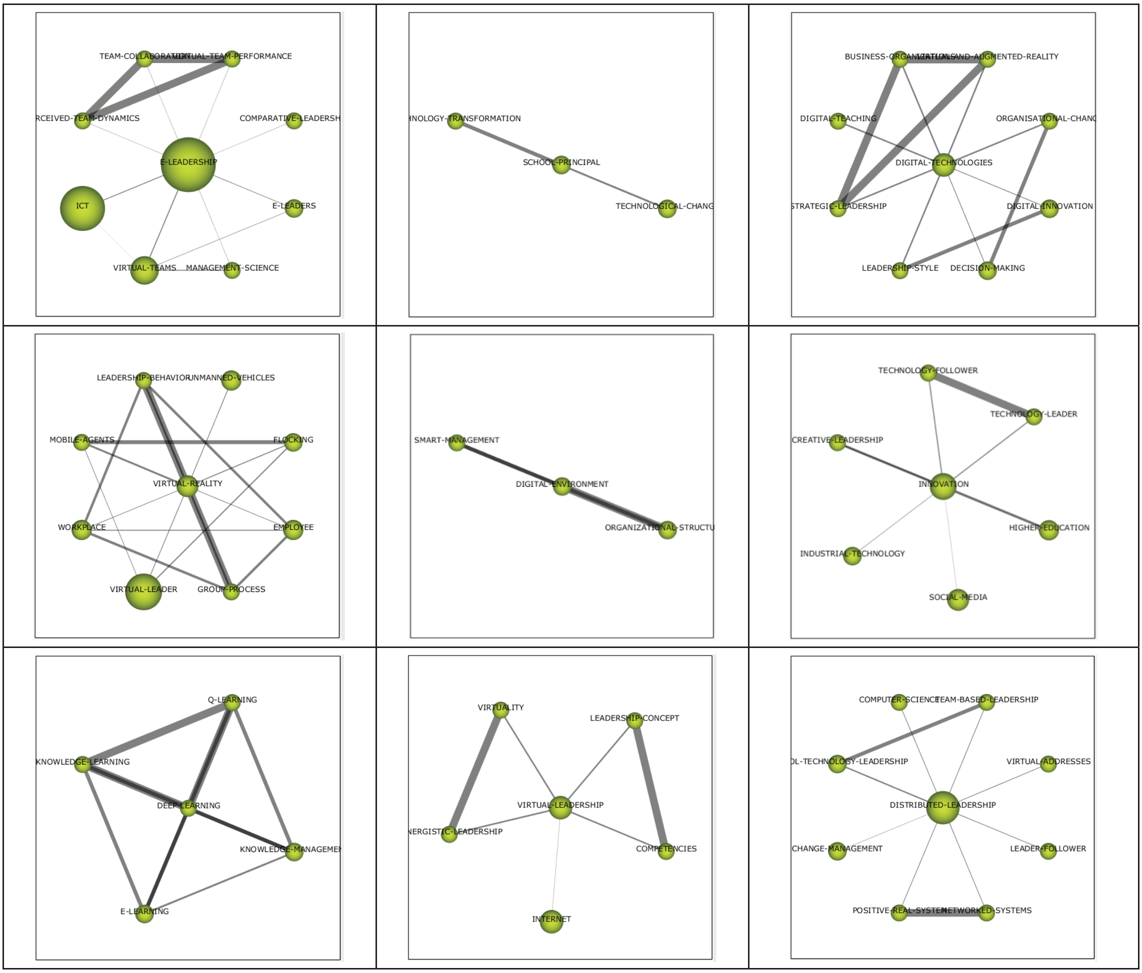


Figure 9. Thematic network structures (2015–2021).

4.2.2. Overlap Fractions

The *overlapping-items graph* shows the number of keywords in each period as well as the newly appeared, lost, and reused keywords in the subsequent period that follows [100]. The *overlapping map* in Figure 10a shows that there were 65 keywords in total used during the first period and that 32 of these keywords did not appear in the second period, whilst 33 of them did. On the other hand, there were 69 keywords used during the second period, of which 43 were used in the following third period, whilst 26 were not. The third period included a total of 172 keywords. While the number of keywords used for the first time during the second period was 36, this was found to be 129 during the third period. However, the similarity index was found to decrease between the periods (from 0.33 to 0.22). The *overlapping-items graph* revealed that the terminology related to digital leadership is getting stronger every year, and new terms have been introduced to the field. The keywords, from left to right, increased from 65 during the first period to 172 during the last period. This significant increase in the number of keywords revealed that those topics of research focusing on digital leadership have diversified and increased cumulatively. The increase in the number of keywords included in each period shows that the studies on digital leadership have constantly been developing, and the disappearing keywords show that the terms have been constantly updated in this research field.

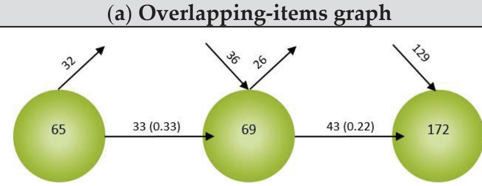
4.2.3. Thematic Evolution Structure

The *thematic evolution map* shown in Figure 10b illustrates the relationship between the patterns of development in the knowledge bases and the digital leadership-focused research themes over the analyzed periods. The size of the spheres shown on the map relates to the number of publications, whilst the thickness of the lines connecting the spheres relates to the correlation between the themes that emerged during each period [43,52]. The *thematic evolution map* shows that seven themes emerged during the first period (1983–2007), which constitutes 28.66% of all the articles included in the analysis. Six of these themes survived in other periods, and one disappeared without making any connection. The *Technology-Leadership* theme that emerged in the first period continued its existence across all three periods. In addition, the *Virtual-Leader* and *Leadership* themes from the first period continued to exist during the second period as well. While the theme of *Leadership-Roles* from the first period was exchanged with the themes of *Virtual-Teams* and *Technology-Leadership* during the second period, the *Technology-Management* theme from the first period was exchanged with the *Technology* and *Student* themes during the second period. The *Economic-And-Social-Effects* theme was exchanged with *Technology* and *Virtual-Leader* themes during the second period, whilst the *Educational-Technology-Leadership* theme from the first period disappeared in the other periods and made no connections with the themes that emerged in the subsequent periods.

Seven themes emerged during the second period (2008–2014), which constitutes 21.34% of the articles analyzed. While three of these themes were from the first period, four of them appeared for the first time in the second period. All the themes from this period were connected with those that emerged during the first or the third period. The *Virtual-Teams* theme was exchanged with the *Technology*, *Virtual-Reality,* and *E-Leadership* themes during the third period, whilst the *Leadership* theme was exchanged with *Education*, *Technology*, *E-Leadership,* and *Virtual-Leadership* themes during the third period. The *Technology* theme continued to exist in the third period and had connections with the *Education*, *Technology-Leadership*, *Distributed-Leadership,* and *School-Principal* themes during the second period. The *Education-Computing* theme evolved into the *Digital-Technologies*, *Digital-Leadership,* and *Deep-Learning* themes, whereas the *E-Leadership* theme, on the other hand, continued to exist during the third period.

The third period (2015–2021) represented 50% of the articles analyzed, and 19 themes emerged during this period. Three of these themes were transferred from the second period; however, 16 appeared for the first time during the third period. Among them, the themes of *Education-Computing*, *Industry*, *Education*, *Digital-Technologies*, *Virtual-Reality*, *Digital-Leadership*, *Distributed-Leadership*, *Virtual-Leadership,* and *Deep-Learning* were connected to those from the previous (second) period. In addition, the themes that appeared only in the third period were found to be *COVID-19*, *Innovation*, *Digital-Twin*, *ISTE-Standards*, *Digital-Environment*, and *Teacher-Leadership*.

(a) Overlapping-items graph



(b) Thematic evolution structure

Period 1 (1983–2007)   Period 2 (2008–2014)   Period 3 (2015–2021)

Figure 10. *Cont.*

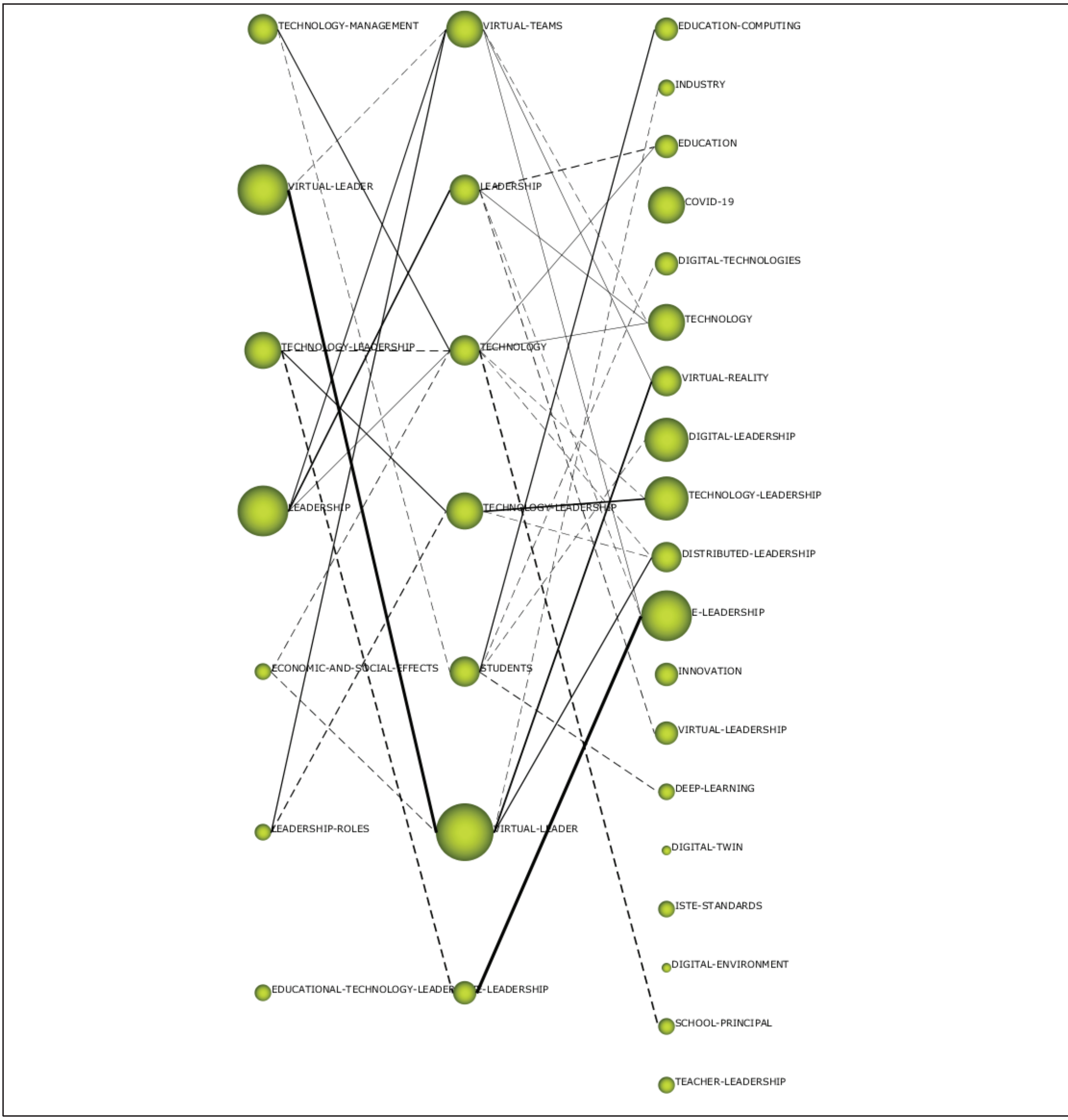


Figure 10. (**a**) Overlapping map and (**b**) thematic evolution map. Source: SciMAT.

5. Discussion

The current study comprehensively investigated the intellectual structure and evolution of digital leadership research by combining bibliometric and science mapping analysis. The results reveal that research interest in digital leadership has increased exponentially. When considering the number (density) of publications, three consecutive time periods were determined to delineate the scope of the digital leadership knowledge base, as well as the emerging research trends in this field of research.

During the first period, comprising the years between 1983 and 2007, the *Technology-Management* and *Economic-And-Social-Effects* themes were found to be the main focus of study. This could be a concrete reflection of the increasing impact of globalization. It may be said that globalization, as an uninterruptedly continuing process from the past to the present, became even more influential after the 1980s. The economic and social impacts of today's digital world are felt intensely in every part of society. In this context, international activities have further clarified the importance of digital transformation and digital leadership and have led to the portrayal of digital leadership as an intercultural type of leadership [101]. The dynamic and complex nature of new technologies has revealed the necessity of developing the existing management competencies of institutions. This important change in the economic, social, and technological environment has further fueled the need for a new type of leadership equipped with high-tech skills. In such a context, digital leaders are expected to act fast and flexibly in new organizational structures while, at the same time, the need to manage the organization's digital transformation process has become prominent [25,102].

Under the influence of globalization and digitalization, artificial intelligence, the internet of things, the sharing economy, and blockchain concepts are likely to become more evident in all areas of socioeconomic life in the coming years. Besides their associations with economics and management, these concepts are very likely to become an integral part of effective business models and global business practices [102]. While the development of digital technologies pushes organizations into a more competitive environment, it has made access to global capital, talent, and other resources much easier [89,103]. Considering the positive/negative socioeconomic effects of digitalization, which have emerged with the influence of technological developments, technology management has become even more crucial. Nambisan et al. [104] emphasized that these developments require the progression of newer theories to better understand the management of these complex processes in the digital world.

In the current study, the *Virtual-Teams, Leadership,* and *Technology* themes were found to be among the main themes of digital leadership research during the second period (2008–2014). In connection with the concepts of *Virtual-Teams* and *virtual leadership*, the term *virtual working* has long become popular in the business world since the development of communication technologies [105,106]. The increasing popularity of *virtual teams* in contemporary organizations has been achieved by successfully structuring the work between teams, increasing the competition, and thus reducing costs [107]. However, some disadvantages of *Virtual Teams* are also noted. For example, less supervision and control in virtual environments, the difficulty of following the flow in the virtual environment, and the fluctuations in employees' commitment to the organization, which are characterized by more freedom, were mentioned among these difficulties [108,109]. In order to overcome these challenges, virtual leaders build trust by using communication technologies, valuing diversity, monitoring team progress using technology, and managing virtual meetings [110]. It has become easier for *virtual leaders* to lead virtual teams thanks to the developments in information technologies, and the use of the internet has become more widespread in business and social areas.

Along with the more general use of the internet towards the end of the 1990s, communication tools using internet infrastructure have also diversified [111]. Thus, teams that could not meet face-to-face due to their spatial distance now have the opportunity to meet within virtual environments. Thanks to the possibilities offered by advanced communication technologies, web-based applications for project management, video conferencing, and program management have been widely used by virtual teams [112]. These emerging technological developments have also had an impact on the academic field, and research on virtual teams and virtual leadership have accelerated. The difficulties caused by the separation of time and space in virtual teams have required leaders to acquire effective management skills in the virtual environment [113,114] because leadership plays an important role in overcoming the challenges faced by virtual teams and realizing the potential benefits. Gilson et al. [3] stated that scientists examining virtual leadership focus on "leader behaviors" and "leader characteristics," as seen in traditional leadership research. Thus, the concept of virtual leadership has found more space both in the business world and in the academic literature.

In the current study, research on digital leadership was found to center around the themes of *COVID-19, Virtual-Reality, Education-Computing,* and *Digital-Technologies* during the third period (2015–2021). The third period of the study, which constituted the years between 2015 and 2021, can be considered an era characterized by the intense impact of technology in every field, as well as wider and easier access to the internet. In addition, towards the end of this period, the world faced the onset of COVID-19, which quickly turned into a global pandemic that triggered health, economic, and social crises. During this challenging process, leadership styles, such as *virtual leadership* or *e-leadership*, have also reshaped the duties and responsibilities faced by leaders at all levels within organizations. Furthermore, artificial intelligence, robotics, the internet of things, blockchain, virtual reality, augmented reality, machine learning, big data, and various forms of digital technology have forced the management and work processes of organizations into a swift move to digital transformation. In this new era known as "Industry 4.0", managers have also been required to transform themselves to become *digital leaders* who can direct digital transformation and become *digital change agents* within their respective organizations [115]. One of the tools that may help to facilitate the digital transformation of digital leaders is *virtual reality* because in the virtual reality context, which is a three-dimensional interactive environment created using computers, users can create and realize different experiences [116].

Virtual reality is a concept with an interdisciplinary nature that combines human sciences with engineering and has a special position in the scientific scheme. The emergence of the virtual reality concept was not sudden but rather was born out of other concepts in previous eras. Today, the use of virtual reality is widespread and ranges from science and technology to human and natural sciences. As such, virtual reality, which is essentially a part of the *Science and Technology of Information and Communication* field, has become more frequently employed within a variety of disciplines, such as psychology, physiology, neurology, robotics, and design [117]. For example, while virtual reality is often used in the field of medical and military education, it may also be applied in limited cases in the field of general education [118], which is also reflected by the number of empirical studies revealed in the field of general education that have focused on virtual reality.

It has been discussed for a long time whether or not *virtual reality* has the potential to revolutionize the field of education. It has been frequently stated in these discussions that virtual reality reveals less harmful results in possible failures and that learners can practice and apply new skills with simulation-based training. Despite these expectations, apart from special training simulators for surgeons, pilots, and military personnel, virtual reality technologies have only been applied in general education and training since 2013, when affordable virtual reality equipment entered the market, making this new technology more accessible to the wider public for the purposes of research and education [119].

Hill [120] stated that virtual reality could be beneficial in gaining leadership experience. Accordingly, a manager can seek to gain experience by practicing within a simulated environment, interacting with a virtual human (an animated character) in a real-world type scenario before facing an interpersonal problem in the office. Thanks to these social simulators, beyond one-on-one interaction, managers can more confidently recognize the complex social environment of the organization. Virtual reality, which is continually developing with breakthroughs in technology, will help to reduce the costs resulting from human mistakes that may arise during on-the-job leadership training.

In the current study, the concept of virtual reality, which is one of the main themes that emerged during the third time period (2015–2021), was found to have associations with augmented reality, artificial intelligence, and machine learning. *Augmented reality* provides an interactive experience with both real and virtual content by adding virtual information to the user's physical environment. Users can also use their own bodies during the augmented reality experience [121,122], as opposed to that of an animated screen-based character. Although there are some concerns about the use of augmented reality in education, the spread of mobile technologies, such as tablet computers, desktop computers, and mobile smartphones, has also influenced the research on augmented reality in education [123,124]. With the spread of advanced augmented reality technologies in educational environments, the previously expensive and complex equipment that was generally unavailable is no longer needed to construct augmented reality experiences [125]. Accordingly, the number of studies focusing on augmented reality applications has increased significantly since 2013 [126], as well as the studies on virtual reality, which is a fact also supported by the findings of the current study. Following 2015, the current study revealed that the subject of augmented reality was more frequently seen in research in the area of digital leadership.

One of the significant findings of our study is that the COVID-19 theme, which emerged during the third time period and is independent of the other two periods, clearly makes the wider influence of the COVID-19 pandemic evident in this regard. The pandemic undoubtedly changed human habits and lifestyles, as well as necessitating the redefinition of modern business strategies. It has also played a significant role in accelerating digital transformation across numerous sectors, such as the economy, health, and also education [127,128]. The pandemic created a challenging work environment for both employees and leaders, and new responsibilities have been added to those of leaders as a result. Among these responsibilities are compelling tasks such as helping staff adapt to changes in their work and social environments [129,130], initiating/accelerating the digital transformation to ensure the survival of the organization [131], and developing overall digital competency [33]. In the new organizational context shaped by the dynamics of the COVID-19 pandemic, digital leaders need to communicate extensively with the other stakeholders of an organization using multiple technology-based tools, such as e-mail, intranet, internet, video conferencing platforms and applications, messaging applications, and various other related tools [132,133].

The COVID-19 pandemic quickly unleashed not only a global health crisis but also an international economic threat. During the pandemic, when active social life was interrupted, business and industrial shutdowns imposed and enforced worldwide to prevent the spread of the virus created unique challenges for managers, employers, and employees alike [134,135]. The effects of these changes that occurred during the pandemic are believed to have survived beyond the pandemic; for example, distance education and learning, the use of digital tools in education, and open universities, which became prominent during the pandemic, are now likely to maintain their ongoing popularity [136–138]. From this perspective, academic research interest in the development of digital leadership skills can be expected to continue, both in the field of education and also in business management.

Limitations

Even though the present study contributed significantly to the literature by identifying the intellectual structure and evolution of digital leadership research, it also bears some limitations, as with any study. The dataset is limited to journal articles focusing on digital leadership indexed on the Scopus database. Although the Scopus database includes a significant number of journals and articles and is considered to be the optimum database for bibliometric and science mapping analysis, the dataset may have inadvertently dismissed some articles published in the relevant research area. Yet, the dismissal of a few of the documents would not change the results significantly thanks to the coword analysis that helps reach a broader scope of related research work.

6. Conclusions

By using digital leadership as an overarching term to refer to any type of technology-focused leadership model, the present study conducted a broad investigation into the scientific evolution of the digital leadership research field and delineated the conceptual and intellectual evolution of its knowledge base since the first article was published in 1983. It is noteworthy that the scientific evolution of the field had parallels with both technological advancements and developments in leadership literature. As evidenced by the periodical science mapping analysis, research started with a focus on the management of technology-integrated organizations as well as the economic and social effects of these new technologies and then moved through to the investigation of leadership practices, particularly with regard to enhancing the operations of virtual teams and, more recently, to leadership practice in coping with the impact of newer digital technologies, such as virtual or artificial reality.

The present study revealed that research interest in digital leadership increased and the themes addressed by researchers diversified significantly and steadily between 2008 and 2021. Despite this widening scope of research, the mind-blowing, revolutionary changes in the contemporary digital world warrant ongoing research to provide fresh insights into the development and practice of best leadership practices that could yield positive outcomes for modern businesses and organizations where constant change has substituted the stable norm. As Kotter [139] eloquently explains, by building new systems or transforming old ones, "only leadership can blast through the many sources of corporate inertia, . . . [and] motivate the actions needed to alter behavior in any significant way", which makes digital leadership a significant model to investigate and practice in the contemporary world of digital breakthroughs. Similarly, the research underlines that leadership is a significant factor in supporting organizations' sustainable working and behavior by increasing its consciousness of sustainability [140], and leaders act as key actors in enabling the successful implementation of organizational sustainability by developing adaptive systems in response to the complex demands from their broader environment [141]. In this regard, the findings of the present study offer significant insights into the future investigations of digital leadership by highlighting the changing research trends and exhibiting the well/under-researched or emerging perspectives.

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Article

The Intersection of Public Policy and Public Access: Digital Inclusion, Digital Literacy Education, and Libraries

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Abstract: This study aims to examine the state of digital inclusion and digital literacy education in Chinese libraries and provide recommendations for improvement. The background section emphasizes the crucial role of libraries in promoting digital inclusion and sustainable development, as well as the challenges and opportunities presented by the current digital landscape in China, such as the digital divide and regional disparities in internet access. To achieve the study's objectives, we conducted analyses of relevant policies, public libraries, and library training programs using a mixed-methods approach. The results highlight the policy landscape, initiatives, and implementation strategies for promoting digital inclusion and literacy education, emphasizing the role of libraries in driving digital inclusion and fostering user engagement. Insights from a university library perspective showcase the role of academic libraries in promoting digital literacy education and training. The findings underscore the importance of digital inclusion and literacy in a digitized society and the crucial role of libraries and academic institutions in achieving these goals. The study advocates for libraries' pivotal role in bridging digital gaps and enhancing literacy to foster an inclusive, equitable digital society and urges policy support.

Keywords: digital inclusion; digital literacy; digital literacy education; libraries; policy

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1. Introduction

1.1. Empowering Sustainable Development: The Crucial Role of Libraries at the Intersection of Information Access, Digital Inclusion, and Policy Objectives

Libraries are recognized as indispensable partners in fostering inclusive and sustainable development by the International Federation of Library Associations and Institutions (IFLA) [1]. Their pivotal role lies in ensuring meaningful access to information, which is essential for economic, social, and environmentally sustainable development. Without such access, informed decision-making, innovation, and full participation in science and culture are hindered, impacting individuals, communities, and global society.

In line with the United Nations 2030 Agenda, libraries are identified as key partners for achieving policy goals. The IFLA advocates for access to information, cultural heritage preservation, universal literacy, and technology within the SDG framework [2]. With a widespread presence, libraries have the unique reach and potential to contribute significantly to various sectors, including livelihoods, quality of life, education, health, gender equality, climate action, and peacebuilding, to foster sustainable development [3].

The pivotal role of libraries in supporting sustainable development initiatives highlights their support for individuals, community institutions, businesses, governments, and civil society organizations in achieving the SDGs. This integral connection between sustainable development, inclusive access to information, and libraries' crucial role is a key message emphasizing their significance [3].

Relevant resources supporting the role of libraries in achieving the SDGs include reports such as "The Role of Libraries in the United Nations Sustainable Development Goals", which provides examples of library projects and partnerships that support the

SDGs [4]. Additionally, "Driving Progress: Libraries and the United Nations' Sustainable Development Goals" highlights how libraries contribute to the SDGs through access to information, literacy promotion, digital inclusion, and cultural preservation [5]. Moreover, a report published by the United Nations titled "Contribution of Libraries to the SDGs—United Nations Partnerships for Sustainable Development" emphasizes the potential of libraries in providing ICT infrastructure, enhancing information literacy skills, and preserving information for future generations [6].

By recognizing libraries as vital actors in achieving sustainable development goals and leveraging their resources and capabilities, we can enhance access to information and empower individuals and communities towards a more inclusive and sustainable future.

1.2. Purpose of the Study and Research Questions

This study focuses on the critical juncture where public policy meets public access within Chinese libraries, with a specific emphasis on their role in promoting digital inclusion and digital literacy education. It aims to explore the intricate connections between these elements and investigate how libraries navigate the complexities of the digital era, acting as linchpins in addressing its challenges and opportunities. By studying the symbiotic relationship between public policy objectives and the role of libraries in facilitating digital inclusion and literacy, we aim to emphasize their vital importance in shaping a more inclusive, informed, and sustainable society.

To achieve this overarching goal, the study will address the following research questions:

- What is the current status of digital inclusion and digital literacy education in China? How knowledgeable, aware, and advanced is the population in addressing these issues?
- How effective are the policies and initiatives implemented by the Chinese government in promoting digital inclusion and enhancing digital literacy education, and what challenges do they face in this process?
- What role do Chinese libraries play in fostering digital inclusion and digital literacy education, and what specific programs, services, and resources do they offer to improve digital skills and access to technology?
- How effective are the digital literacy education programs offered by Chinese libraries? What strategies, content, and approaches are utilized to develop digital skills and knowledge among individuals?
- Based on the findings, what recommendations can be proposed to enhance digital inclusion and digital literacy education in Chinese libraries, particularly regarding service improvements, collaboration with stakeholders, and advocating for supportive policies?

Employing a mixed-methods approach, this study will provide an in-depth examination of digital literacy policies, library-based digital services, and the prevailing conditions of digital literacy education in China. The objective is not only to assess the current situation but also to offer practical insights for policymakers, library professionals, and stakeholders committed to narrowing the digital divide and advancing digital literacy education in Chinese libraries.

By addressing these key aspects, the study ultimately seeks to facilitate equal access to digital technologies and cultivate essential digital competencies among all members of China's digital society.

2. Literature Review

2.1. Background and Significance of Digital Inclusion, Digital Literacy Education, and Libraries

Digital inclusion is a concept that focuses on providing everyone with equal access to and opportunities to engage with digital technologies. It encompasses various elements, including motivation, self-regulation, feedback, collaboration, and lifelong learning [7]. The International Telecommunication Union (ITU) report, "Digital Inclusion: The Global Effort to Bring Everyone Online", examines the current state of digital inclusion and the challenges and opportunities for achieving universal access to the internet. The report defines digital inclusion as "the ability of individuals and groups to access and use information and communication technologies (ICTs)". It argues that digital inclusion is essential for achieving the Sustainable Development Goals (SDGs) and empowering people to participate in a digital society. The report provides data and statistics on the digital divide, including the fact that 3.6 billion people remain offline, particularly in developing countries. It identifies four key dimensions of digital inclusion: availability, affordability, skills, and relevance [8].

While digital inclusion focuses on ensuring equal access and opportunities for individuals to engage with digital technologies, digital literacy encompasses the knowledge, skills, and abilities to effectively navigate, evaluate, and utilize digital information [9]. Digital inclusion refers to the capacity of individuals and groups to effectively access and utilize information and communication technologies (ICTs) for various purposes, such as education, healthcare, employment, entertainment, and civic engagement. It plays a crucial role in achieving the Sustainable Development Goals (SDGs) and empowering individuals to actively participate in the digital society [10]. Effective digital literacy plays a crucial role in enabling individuals to navigate the digital landscape, evaluate the credibility of information, communicate effectively, and utilize digital tools to solve problems and achieve goals. Therefore, prioritizing effective digital literacy education is essential [11,12]. Digital literacy education emphasizes the development of digital skills and an understanding of the social and cultural practices associated with digital media use. The objectives of digital literacy education can vary, from preparing individuals for participation in the knowledge economy to promoting democratic citizenship and social empowerment [13].

"The Digital Literacy Imperative" argues that digital literacy is essential for global citizens to communicate, find employment, receive comprehensive education, and socialize [14]. "Understanding and Developing Digital Literacy" provides a comprehensive guide for teachers and educational managers on integrating digital literacy into curricula [15]. UNESCO has found that 21st-century skills are crucial for lifelong learning and employability [16]. The ultimate goal of digital literacy education is to provide individuals lacking digital skills with informal learning opportunities and access to digital resources, thereby facilitating their connection and inclusion in the digital world [17]. Gerald Leitner, the Secretary General of the International Federation of Library Associations and Institutions (IFLA), emphasizes that any effort to promote digital inclusion needs to consider connectivity, content, and competence. Libraries, as public spaces in communities, storehouses, and portals to content, and experienced educators in information literacy, have a unique role to play in promoting digital inclusion and enhancing digital literacy. Libraries should advocate for inclusion in wider government strategies and receive the necessary legal and financial support [18].

"Innovation in Library Digital Inclusion Initiatives: Insights from the 2022 World Summit on the Information Society Forum" showcases how public libraries are leading the way in providing a wide range of technologies and digital content to their communities [19]. "Public Libraries Lead the Way to Digital Inclusion" summarizes key findings from a survey conducted by IMLS on how public libraries help build digitally inclusive communities [20]. A project by READ Nepal provides free access to computers and the internet at community libraries and resource centers, helping over 10,000 girls and women in rural areas develop their digital skills and confidence [21].

In the era of digital technology, digital inclusion aims to solve two major problems: promoting public access to the Internet and sharing the achievements of technological civilization, as well as helping citizens navigate the Internet freely without getting lost [18]. As community information centers, libraries provide diverse information and knowledge to the public and play a significant role in digital inclusion [18].

Considering the increasing importance of digital inclusion and digital literacy education, it is crucial to investigate the current situation of these matters in Chinese society, with a specific focus on the role of libraries in promoting digital inclusion and enhancing digital literacy. Gaining insights into the policies and initiatives implemented to address these challenges is pivotal for devising effective strategies and recommendations to enable libraries to effectively fulfill their role as vital facilitators of digital inclusion and digital literacy education.

2.2. Overview of the Current Digital Landscape in China

China has witnessed a rapid digital transformation in the past few decades, with significant advancements in internet access and adoption. With its vast population, China has emerged as a global leader in terms of internet penetration and digital technologies. The country's digital landscape has experienced substantial growth, characterized by a large number of internet users and high mobile technology penetration. As of June 2023, China had reached 1.079 billion internet users, with a penetration rate of approximately 76.4% (CNNIC, 2023) [22]. Additionally, China has made significant strides in expanding its digital infrastructure, particularly in mobile technology [22].

Mobile technology has become the primary means of internet connectivity in China. As of June, there were 2.937 million operational 5G base stations, serving 676 million users with 5G mobile phones. Furthermore, the three major telecommunications companies have interconnected 2.123 billion cellular Internet of Things (IoT) devices. China's technological prowess is exemplified by the deployment of 20.29 million 10G PON ports, providing gigabit services. The adoption of IPv6 is also on the rise, with 767 million active users utilizing IPv6, and mobile networks accounting for over 50% of IPv6 traffic.

The utilization of digital resources has also experienced significant growth, with mobile internet traffic reaching 142.3 billion gigabytes by June, reflecting a 14.6% year-on-year increase. The market hosts a robust presence of 2.6 million active applications, offering comprehensive solutions for users' daily learning, professional endeavors, and lifestyle requirements. These developments have greatly enhanced convenience and the provision of services in China.

The report from the Ministry of Education of China outlines the government's vision and policies for deepening digital transformation and building a bright future for education [23]. It shows that China has been actively involved in the creation and promotion of the UN2030 SDGs (Sustainable Development Goals), with a particular focus on access to information, safeguarding cultural heritage, universal literacy, and access to information and communication technologies (ICT). The report from Statista presents variations in China's urbanization rate, per capita GDP, education level, and Gini coefficient across different regions [24]. It reveals significant regional gaps in economic and social development in China, which are also reflected in the digital divide. The article from Xiang and Stillwell (2023) discusses the predominant reliance on mobile phones among rural internet users in China to access online services [25]. It highlights the affordability and convenience of mobile phones for rural residents in contrast to desktop and laptop computers. However, it also acknowledges the limitations of mobile phones, such as restricted functionality and lower quality compared to computers. The website China.org.cn features various news and reports on China's efforts to enhance digital literacy among different groups of people [26]. It showcases China's implementation of various policies and programs to improve the digital skills and competencies of its citizens, especially in rural areas, ethnic regions, and underprivileged groups.

The digital landscape in China presents both challenges and opportunities. On the one hand, the widespread adoption of digital technologies has revolutionized various sectors, including e-commerce, fintech, and mobile payments. Platforms such as Alibaba's Taobao and Tencent's WeChat have transformed online shopping and communication. The Chinese government has actively embraced digital technology, implementing initiatives to improve national digital literacy and skills, accelerate digital development, and build network power and a digital China. The government has established the "Action Outline to Improve National Digital Literacy and Skills" [27] to enhance citizens' abilities to navigate the digital landscape, including acquiring the necessary skills to access, produce, utilize, evaluate, and interact with digital content. These actions aim to foster a digitally empowered population and align with the broader national goals of advancing overall digital capabilities and achieving shared prosperity.

However, despite the impressive growth in internet access, China still faces unique challenges in terms of digital inclusion and digital literacy. Regional disparities in internet access and skills persist, with urban areas benefiting from better infrastructure and higher digital literacy rates compared to rural areas [28]. Furthermore, there is a significant digital divide among different population groups, including the elderly, low-income individuals, and those with limited education [29]. Although China has made progress in equalizing urban-rural digital access opportunities, the digital application gap resulting from differences in residents' digital participation level, application structure capacity, and industrial digitalization level has become more pronounced. According to an analysis of nearly 100,000 respondents in the China Household Tracking Survey (2014–2018), data from 2018 reveals that only about 30% of the rural population utilized the internet for work, learning, and business activities, significantly lagging behind urban residents by nearly 20% [30].

Addressing these challenges is crucial for promoting digital inclusion and enhancing digital literacy in China. It requires collaborative efforts from various stakeholders, including government bodies, libraries, educational institutions, and civil society organizations, to bridge the digital divide and ensure equitable access to digital technologies and the necessary skills for their effective utilization across different regions and demographics [18]. Libraries, in particular, play a vital role in this process by providing access to information, resources, and training programs for the public [18].

In conclusion, by understanding and addressing the challenges related to digital inclusion and digital literacy education, China can harness the potential benefits of its digital landscape and ensure that all individuals have equal opportunities to participate in and benefit from the digital revolution.

3. Materials and Methods

3.1. Materials

3.1.1. Digital Literacy Policy

To investigate the policies and regulations related to digital literacy, we conducted searches in the Peking University Law Database [31], also known as PKULaw. Established in 1985 at Peking University, this legal retrieval system is considered the primary database for Chinese law, making it a commonly used database for policy analysis and research. PKULaw provides comprehensive coverage of Chinese policy and regulations, including those related to digital literacy. With a data volume exceeding 5 million articles, it offers extensive access to legal information.

By performing precise searches using keywords such as "information literacy", "digital literacy", and "digital inclusion", primarily focusing on titles, we obtained 69 relevant local working documents, 2 departmental regulations, and 1 party internal rule and regulation. In addition to the Peking University Law Database, we also supplemented our search for policy data by utilizing search engines. This allowed us to gather a broader range of information and ensure the comprehensiveness of our analysis.

By utilizing both the Peking University Law Database and conducting supplementary searches through search engines, we ensured a comprehensive approach to collecting policy data related to digital literacy. This ensured that we had access to a wide range of policies and regulations in this specific context, facilitating a thorough analysis of the digital literacy landscape in China.

3.1.2. First-Class Public Library and Evaluation Criteria

The assessment and grading of public libraries at or above the county level in China are conducted every four years. This assessment provides an important means for the comprehensive evaluation of library services, the analysis of the status of public library work, and the promotion of the standardization and normalization of library operations.

Sponsored by the Office of the Ministry of Culture and Tourism, the results of the seventh national assessment and grading of public libraries at or above the county level were announced in November 2023 [32]. Among the libraries included in the assessment, there were 1302 first-class public libraries, a significant increase compared to the previous assessment conducted in May 2018, where there were 953 first-class public libraries [33].

In our analysis, we focused on the evaluation criteria for public libraries, particularly the ones related to digital services. These criteria play a crucial role in assessing the level of digital inclusion and digital literacy within libraries.

3.1.3. Digital Literacy Education and Library Training Program at Wuhan University Library

Digital skills have become an essential part of contemporary scholarship and education. Academic libraries, as vital information resource centers of universities, offer digital academic resources and services to students, teachers, and researchers. In addition, academic libraries undertake the crucial task of fostering digital literacy.

According to the basic statistical information of Chinese university libraries, 983 university libraries disclosed the number of participants in information literacy education courses or training programs organized by libraries in 2020. The median number of participants was 3000, and the Wuhan University Library had the highest number of students enrolled in information literacy education courses, with 185,803 students [34]. The Wuhan University Library offers a variety of digital literacy training programs with a strong emphasis on innovation, covering a wide range of topics from basic domestic and foreign database usage to 3D printing. Furthermore, there are many corresponding competitions to promote the implementation of training programs [35].

In addition, the Wuhan University Library can leverage the expertise and teaching of the Library Science program at Wuhan University. The Library Science program at Wuhan University has a long history, broad coverage, and strong academic strength. With over a century of history, it is the largest information management institution in China in terms of scale and coverage. This gives the library inherent advantages in providing education and training in the field of digital literacy.

Therefore, this article takes the digital literacy training program at the Wuhan University Library as a typical research object. A web scraping tool was used to collect training program data organized by the Wuhan University Library. The data spans from February 2007 to March 2023, with a total of over 2700 training program records.

3.2. Methods

In this study, we employed a mixed-methods approach to comprehensively analyze the policies related to digital inclusion and digital literacy education in China, high-ranking Chinese public libraries, and library training programs.

Through the qualitative component of our research, we conducted a thorough review and analysis of policy documents to understand the goals, implementation strategies, and monitoring mechanisms. We also identified any challenges or gaps in the policies. The qualitative approach facilitated our understanding of the policy context and the roles of key stakeholders in policy development and implementation.

For the quantitative component, we conducted a detailed analysis of high-ranking Chinese public libraries, examining key indicators of digital inclusion and digital literacy. Using data visualization techniques such as data maps, we presented the spatial distribution of these libraries. This quantitative analysis helped us understand the performance of high-ranking libraries in terms of digital inclusion and digital literacy, as well as identify regional variations.

Furthermore, we adopted a mixed-methods approach to analyze library training programs. We utilized the TF-IDF (term frequency–inverse document frequency) method, a qualitative technique, to extract keywords and then employed quantitative statistical analysis to determine the importance of these keywords within the text. This combination of qualitative and quantitative methods enabled us to gain an in-depth understanding of the core content of library training programs and their significant impact on digital literacy education.

By employing this mixed-methods approach, our study leveraged the strengths of qualitative and quantitative methods to comprehensively assess the current status and challenges of digital inclusion and digital literacy education in China.

3.2.1. Policy Analysis

Policy analysis regarding digital inclusion and digital literacy education in China heavily relied on manual review due to the limited number of policy documents. The following steps were taken to conduct the analysis (as illustrated in Figure 1):

- Reviewing existing policies and regulations: National-level laws, government initiatives, and guidelines issued by relevant authorities were examined to gain insights into the policies and regulations related to digital inclusion and digital literacy education in China.
- Identifying key stakeholders: The involvement of key stakeholders in shaping and implementing policies related to digital inclusion and digital literacy education in China was determined.
- Assessing policy goals and objectives: The goals and objectives stated in policies and regulations pertaining to digital inclusion and digital literacy education were analyzed. Special attention was given to initiatives aimed at reducing the digital divide, promoting equitable access to information and technology, and enhancing digital skills and literacy across the population.
- Evaluating implementation strategies: The strategies and measures outlined in policies for achieving digital inclusion and promoting digital literacy education were evaluated.
- Studying monitoring and evaluation mechanisms: The mechanisms in place for monitoring and evaluating the effectiveness and impact of policies related to digital inclusion and digital literacy education in China were investigated.
- Analyzing gaps and challenges: Any gaps or challenges within the policy landscape for digital inclusion and digital literacy education in China were identified.

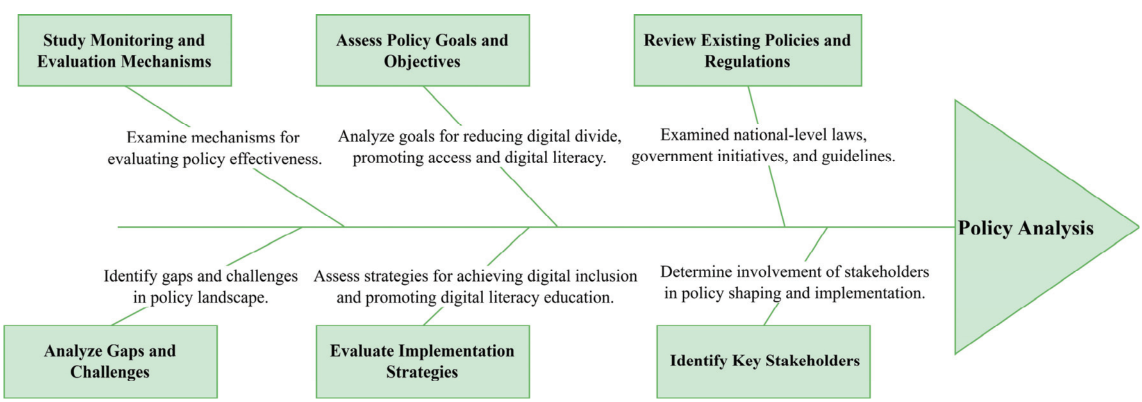

Figure 1. Policy analysis process for digital inclusion and digital literacy education in China.

By following these steps, a comprehensive analysis of policies related to digital inclusion and digital literacy education in China was conducted, despite the limited number of policy documents available for review.

3.2.2. Analysis of Digital Inclusion and Digital Literacy in High-Ranking Chinese Public Libraries

To analyze the extent of digital inclusion and digital literacy in Chinese public libraries, we conducted an analysis of the evaluation criteria for libraries. Specifically, we focused on the assessment criteria outlined in the evaluation standards. These libraries exemplify the highest levels of digital literacy and advancement [36].

On 26 May 2022, the Ministry of Culture and Tourism of China conducted the latest round of library grading evaluations, known as the seventh national evaluation for public libraries above the county level [33]. The evaluation process was based on assessment criteria established by the Ministry of Culture and Tourism, encompassing provincial-level libraries, vice-provincial and prefectural-level libraries, county-level libraries, and children's libraries. The evaluation data predominantly covered the assessment period from 2018 to 2021, unless stated otherwise in the criteria. Our analysis primarily focused on the assessment criteria pertaining to digital services outlined in these standards.

3.2.3. Library Training Program Analysis

Undoubtedly, the incorporation of digital inclusion into the valuable public information services provided by academic libraries is essential. This integration aims to ensure equitable access to digital information and knowledge for diverse user groups [18].

To conduct a comprehensive analysis of the library training programs, we employed the term frequency–inverse document frequency (TF-IDF) technique for keyword extraction. TF-IDF is a widely used weighting technique in information processing and data mining that calculates the importance of a term in the entire corpus based on its frequency in the text and its document frequency in the dataset [37]. This statistical method effectively filters out common and irrelevant words while retaining significant terms that have a substantial impact on the entire text.

Before conducting the analysis, we preprocessed the data using a Python program. This preprocessing involved tokenization, the removal of stop words, and importing a keyword dictionary [38]. These steps ensured that the analysis focused on relevant keywords that reflected the core content of the library training programs' impact on digital literacy education and training.

4. Results

4.1. Results of Policy Analysis

To analyze the policy landscape of digital inclusion and digital literacy education in China, we conducted a review of national policies and frameworks in these areas. The key policies and initiatives that were identified include the "Action Plan for Enhancing National Digital Literacy and Skills" [39] and the release of educational industry standards for "Teacher Digital Literacy" by the Ministry of Education [40]. These policies and initiatives aim to promote digital literacy and skills across the population and drive the development of digital inclusion efforts.

In our analysis, we examined the following aspects of these policies: stakeholders involved, goals and objectives, implementation strategies, and monitoring and evaluation mechanisms. The details of our analysis are presented in Table 1.

Table 1. Policy landscape analysis for digital inclusion and digital literacy education in China.

Policy	Stakeholders	Goals and Objectives	Implementation Strategies	Monitoring and Evaluation Mechanisms
"Action Plan for Enhancing National Digital Literacy and Skills" [39]	Office of the Central Cybersecurity and Information Technology Commission; Central Party School (National School of Administration); Ministry of Education, Science, and Technology; Ministry of Industry and Information Technology; Ministry of Civil Affairs; professional institutions; etc.	Enhance digital literacy and skills among the entire population.	Organizing the "National Digital Literacy and Skills Enhancement Month" initiative, promoting citizen digital literacy and skills through training, innovation contests, and assessments, inspiring digital innovation among the public [41–44].	Develop a comprehensive action plan for enhancing national digital literacy and skills that includes the establishment of an evaluation framework. This plan aims to periodically conduct nationwide monitoring surveys and assessments on digital literacy and skills development. The results of these assessments will be published in reports to guide regional and industry-level initiatives. Furthermore, the plan will support pilot projects in select regions and industries to explore innovative mechanisms and best practices. These pilot projects will serve as replicable and scalable models, ultimately driving an overall improvement in digital literacy and skills for all [27].
"Teacher Digital Literacy" [40]	Provincial Education Departments, Education Committees of Autonomous Regions and Direct-Control Municipalities, Education Bureaus of Planned and Single-Planned Cities and teachers.	Improve teachers' awareness, abilities, and responsibilities in utilizing digital technology.	As an education industry standard.	This standard will be used for the training and evaluation of teachers' digital literacy.

4.2. Results of Digital Inclusion and Digital Literacy in High-Ranking Chinese Public Libraries

Regarding the evaluation criteria for libraries at different levels, digital services account for approximately 20% of the total score, totaling 55 points out of a maximum of 300. Digital services are therefore the second most significant aspect, following basic services.

Website Services (15 points)

a. Possessing an independent domain for the library's website and ensuring its functional completeness (5 points).
b. Annual website visits (in 10,000 page views) (10 points).

New Media Services (20 points)

a. Maintaining official accounts on new media platforms such as Weibo and WeChat and offering information push services to users (5 points).
b. Annual number of information pushes (5 points).
c. Annual views of pushed information (in 10,000 views) (5 points).
d. Providing mobile library services such as reservations, retrieval, and borrowing through apps, mini-programs, WeChat official accounts, and other new media platforms (5 points).
e. Bonus point explanation: Having multiple new media service channels and achieving excellent service results (10 points).

Annual Digital Resource Service Volume (20 points)

a. Annual views of digital resources in the library's collection (in 10,000 views) (10 points).
b. Annual downloads of digital resources in the library's collection (in articles/copies) (10 points).

Therefore, first-class public libraries represent the most digitally literate and advanced segment of Chinese libraries. To analyze this, we utilized statistical data provided by the Ministry of Culture and Tourism, focusing specifically on primary libraries and their respective provinces. We imported the data into a mapping package using Python programming, and the resulting visualization is presented in Figure 2.

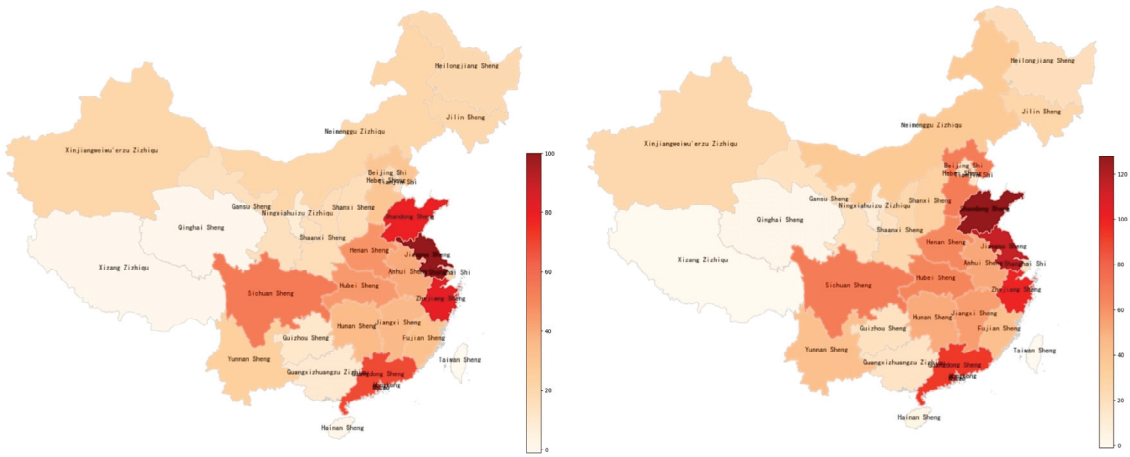

Figure 2. The number of first-class libraries in various regions of China.

4.3. Results of the Library Training Program Analysis

The results of the analysis of the library training program are presented in Table 2, which displays the TF-IDF scores for each keyword in the text. A higher score indicates greater significance for the keyword in the text.

Table 2. Library training project TF-IDF processing results—keywords and weights.

No.	Keywords	Weights	No.	Keywords	Weights
1	Database	0.2692	11	Lecture	0.079
2	Library	0.2309	12	Contribution	0.078
3	Preview	0.1419	13	Reading	0.0779
4	Document	0.1156	14	Contest	0.0773
5	Branch library	0.1141	15	Introduction	0.0739
6	Journal	0.11	16	Scientific research	0.0707
7	Notification	0.1017	17	Skill	0.0694
8	Arrangement	0.0945	18	Platform	0.0664
9	Music	0.0854	19	Tracks	0.0604
10	Exploit	0.0791	20	Academic search	0.0585

The keywords that were identified include the following: Database, Library, Preview, Document, Branch library, Journal, Notification, Arrangement, Music, Exploit, Lecture, Contribution, Reading, Contest, Introduction, Scientific research, Skill, Platform, Tracks, and Academic search. These keywords highlight the core content of the digital literacy education and training provided by Wuhan University Library.

5. Discussion

5.1. Promoting Digital Inclusion and Literacy: Policies, Initiatives, and Implementation Strategies

5.1.1. Policy Landscape of Digital Inclusion and Digital Literacy Education in China

In our comprehensive analysis of the policy landscape for digital inclusion and literacy education in China, we explore a wide range of national policies, initiatives, implementation strategies, and monitoring and evaluation mechanisms. Our study is significant because it focuses on enhancing multifaceted abilities across diverse user groups, aligning with Lankshear and Knobel's (2015) perspective that digital literacy encompasses not only information-related skills but also popular digital culture artifacts [45].

The "Action Plan for Enhancing National Digital Literacy and Skills" is a key policy that emphasizes the importance of developing digital literacy and skills universally [39].

This plan establishes clear targets for fostering digital inclusion and literacy and serves as an overarching framework guiding various initiatives.

Implementation strategies have been dynamic and collaborative, as evidenced by the "National Digital Literacy and Skills Enhancement Month" initiative coordinated by the Central Cyberspace Affairs Commission and 15 other departments [41]. This initiative coordinates efforts nationwide to enhance the digital capabilities of the population.

A significant aspect of this policy landscape is the Ministry of Education's release of educational industry standards for "Teacher Digital Literacy" [40]. These standards align with the emphasis placed on libraries and adult-targeted policies by Huang (2021) and Eynon (2021), respectively [46,47]. They are designed to support the national education digitalization strategy and enhance teachers' proficiency in using digital technology for instructional purposes.

To ensure the effectiveness of these interventions, robust monitoring and evaluation systems have been established. The "Action Plan" includes an evaluation framework [27] that conducts nationwide surveys and assessments to track progress in digital literacy and skills development. The findings from these assessments are published in reports, informing and guiding regional and sector-specific initiatives.

Pilot projects launched in select regions and industries further contribute to the innovation and refinement of best practices. These projects serve as replicable models, aiming to scale up successful strategies and drive widespread improvement in digital literacy and inclusion across all sectors.

By comparing our findings with previous research and international benchmarks, such as those set by the International Society for Technology in Education (ISTE), our study provides a comprehensive overview of China's policy environment for digital inclusion and literacy education [48]. It highlights how current policies, when effectively implemented and systematically evaluated, play a critical role in promoting digital literacy and inclusivity within an increasingly digital society. Furthermore, it reflects on the Chinese Ministry of Education's concrete steps, such as the "National Project for Enhancing the Information Technology Application Capabilities of Teachers", which demonstrate a commitment to equipping educators with the necessary competencies for navigating the digital realm in teaching, learning analytics, instructional design, pedagogical guidance, and academic assessment [49].

5.1.2. Regional and Local Initiatives: Fostering Digital Inclusion and Literacy Education at the Grassroots Level

During the promotion period, a total of 64,000 themed activities were planned and conducted nationwide, with over 52 million participants. More than 250,000 digital teaching resources were made available, and nearly 58,000 articles were produced and reported. These resources received nearly 630 million online clicks, effectively promoting the collaborative construction and sharing of digital development achievements among the general public, thereby supporting economic and social development and improving people's well-being [42].

In addition to national-level initiatives, various regions and local governments in China have implemented plans and measures to promote digital inclusion and literacy within their jurisdictions. For example, to further enhance the digital adaptability, competence, and creativity of the entire population in the Yangtze River Delta region and empower higher-quality integrated development in the region, the Shanghai Municipal Committee's Cyberspace Administration, along with the cyberspace administrations of Jiangsu Province, Zhejiang Province, and Anhui Province, jointly issued the "Initiative for the Joint Action on Digital Literacy and Skills Enhancement in the Yangtze River Delta in 2023" during the directors' meeting of the Cyberspace Administration in the Yangtze River Delta on 27 November [43].

Tianjin Municipality released the "Work Plan for Improving Digital Literacy and Skills for All in Tianjin in 2023" and the "Key Points of Work for Improving Digital Literacy and

Skills for All in Tianjin in 2023". The leaders of the Municipal Committee's Cyberspace Administration, the Municipal Education Commission, and the Municipal Association for Science and Technology presented certificates to three national training bases for digital literacy and skills, namely Tianjin University, Tianjin Vocational University, and the Digital Security Research Institute of Tianjin Smart City [44].

Regional and local initiatives promoting digital inclusion and digital literacy education have a wide-reaching impact. These initiatives are implemented at the grassroots level, targeting individuals and communities that may face barriers to accessing and utilizing digital technologies. By providing training, resources, and support, these initiatives aim to bridge the digital divide and empower individuals to fully participate in the digital age.

5.1.3. Impact of Policies and Collaborative Implementation of Digital Inclusion Initiatives

Using the "Action Plan to Enhance Digital Literacy and Skills for All" as an example, this action plan was referenced by three central regulations, including institutions such as the Office of the Central Committee for Cybersecurity and Informatization, the Ministry of Agriculture and Rural Affairs, and the China Association for Science and Technology. In addition, six local regulations also referenced this action plan, involving institutions such as the Jiangsu Provincial Department of Commerce, the Sichuan Provincial Department of Housing and Urban-Rural Development, the Hainan Association for Science and Technology, the Changsha Bureau of Data Resource Management, the Beijing Municipal Bureau of Economy and Information Technology, and the Office of the Joint Meeting of High-skilled Talent Work in Chongqing.

The coordination among central institutions and the proactive response of local governments to national policies have facilitated the swift implementation of digital inclusion and literacy initiatives. This reflects the effectiveness of the policy in achieving its goals within a short timeframe.

5.1.4. Policy Objectives, Goals, and Gaps in Implementation

The government aims to build a strong digital nation and accelerate the development of robust digital infrastructure. The objectives include enhancing the levels of the digital economy, digital society, and digital government and improving people's sense of achievement. However, challenges such as a lack of top-level design, a digital divide, inadequate resources, limited training systems, and a need to enhance awareness of digital ethics standards exist. Urgent efforts are required to refine policy measures and enhance the digital literacy and skills of the entire population.

By 2025, significant improvement in digital literacy and skills is expected, reaching the levels of developed countries. The development environment for digital literacy will be optimized, a basic system for high-quality digital resource supply will be established, and a nationwide lifelong digital learning system will be constructed. The digital divide will be bridged, workers' digital skills will be enhanced, and a smart and harmonious digital life will be achieved. Looking ahead to 2035, even higher levels of digital literacy and skills for the entire population are anticipated. High-end digital talents will flourish, playing a leading role in digital innovation and entrepreneurship and supporting the construction of a strong digital nation and a smart society [27].

By addressing these aspects of policy analysis, a comprehensive understanding of the policy landscape for digital inclusion and digital literacy education in China was achieved, despite the limited number of policy documents available for review.

5.2. Libraries Driving Digital Inclusion and User Engagement

5.2.1. Libraries as Catalysts for Social and Digital Inclusion

Libraries play a vital role in promoting social and digital inclusion by serving as community hubs and providing access to resources, information, and technology. They act as inclusive spaces, welcoming diverse communities and offering equal access to information and resources. By doing so, libraries bridge the gap between individuals and the digital world. The library is aligned with the global sustainability agenda, working with other stakeholders to achieve the Sustainable Development Goals [50].

In terms of social inclusion, libraries create a sense of belonging by offering a wide range of materials, programs, and services that cater to the needs and interests of different community members [51]. They ensure equal access to information and resources, regardless of an individual's background. Moreover, libraries offer free internet access, technology training, and digital resources, enabling individuals from all socioeconomic backgrounds to participate and engage in an increasingly digitalized society.

Furthermore, libraries contribute to digital inclusion by providing digital literacy education and skill development opportunities. They offer workshops, classes, and one-on-one assistance to help individuals acquire the necessary skills to navigate and utilize digital technologies effectively [52]. By promoting digital literacy, libraries empower individuals to access online information, communicate digitally, and engage in e-learning. This is particularly beneficial for marginalized groups who face barriers to accessing digital resources and technology, bridging the digital divide.

The analysis highlights the correlation between the digitalization efforts of leading public libraries and their impact on enhancing digital literacy among the population. It suggests that libraries at the forefront of digitalization initiatives are better equipped to provide cutting-edge digital services and resources, thus driving the digital literacy and skills development of their patrons. These libraries serve as models for other libraries, inspiring them to enhance their digitalization efforts and expand their digital services, ultimately advancing digital inclusion and literacy on a broader scale [53].

In conclusion, libraries play a crucial role in promoting both social inclusion and digital inclusion. Their diverse programs and resources create a welcoming environment for all community members, while also providing access to digital tools and technologies. The digitalization efforts of leading public libraries positively contribute to enhancing the digital literacy of the population, emphasizing the important role libraries play in promoting digital inclusion [54].

5.2.2. The Significance of Digital Services in Libraries for Improved User Experience and Engagement

Digital services play a vital role in library settings, with particular emphasis on website services, new media services, and digital resource services [55]. These services are instrumental in enhancing the user experience, increasing website visits, and boosting download counts.

Website services are essential for libraries, as they provide the primary platform for users to access information, resources, and services. It is imperative for libraries to have an independent domain for their website and ensure its functional completeness. This enables users to navigate the website easily and efficiently to find the desired information or resources.

Furthermore, the volume of website visits per year serves as a significant metric for evaluating the effectiveness and popularity of the library's online presence. High website visit volumes indicate a strong user interest in the library's offerings and a positive user experience. Therefore, libraries should strive to attract and retain website visitors through engaging content, intuitive navigation, and responsive design.

New media services, such as official accounts on popular platforms like Weibo and WeChat, provide an additional avenue for libraries to connect with their users. By providing information push services through these platforms, libraries can effectively communicate with their users and keep them informed about library events, new resources, and other relevant updates. The annual amount of information pushed and the browsing volume of pushed information are key indicators of the reach and engagement of the library's new media services.

In addition to social media platforms, libraries can also provide mobile library services through apps, mini-programs, and WeChat official accounts. These digital channels allow users to perform various library functions, such as reserving, retrieving, and borrowing materials. Such convenience and accessibility contribute to a positive user experience and encourage users to utilize library services more frequently.

Digital resource services encompass the library's collection of digital resources, such as e-books, e-journals, and online databases. The annual browsing volume and download count of these resources are important measures of their utilization by library users. High numbers in these metrics indicate not only the popularity of the library's digital collection but also the effectiveness of digital literacy initiatives in promoting access and usage.

In conclusion, prioritizing digital services in libraries, particularly website services, new media services, and digital resource services, is crucial for enhancing the user experience, increasing website visits, and maximizing the utilization of digital resources. By focusing on these services, libraries can adapt to the evolving needs and preferences of their users in the digital age, ultimately fostering a more inclusive and effective information environment.

5.2.3. Bridging the Gap: Geographic Distribution of First-Class Public Libraries Reflects Progress in Digital Inclusion

The distribution of first-class public libraries in China reveals a nuanced landscape of digital inclusivity progress, particularly concentrated in economically vibrant southeast coastal provinces characterized by strong economies and large populations. These regions have allocated significant resources for the development of cutting-edge library infrastructure and services, including the establishment of first-class public libraries. These libraries epitomize the pinnacle of China's public library system's digital innovation and technological integration.

However, an interesting pattern emerges when considering the growth trajectory of these libraries in other regions of the country. Despite existing economic disparities, such as per capita GDP, some provinces, particularly those in northern China, have made significant strides in expanding their library networks. This commitment to expanding library facilities and increasing access to digital resources and services indicates strategic efforts to bridge the digital divide and cultivate digital literacy among residents.

Shandong Province serves as a notable example, as the number of first-class public libraries has significantly increased in recent years, driven by strong local government initiatives. The number of first-level libraries in Shandong Province has risen from 79 to 128, ranking first nationwide. This exponential growth highlights the province's proactive stance in promoting knowledge acquisition and meeting the evolving digital literacy needs of its population.

Against this backdrop, the significant increase in first-class public libraries in regions like Shandong and Hebei represents a major shift in policies toward equitably providing library services across different geographical areas. This signifies that investment in library modernization is no longer limited to traditionally prosperous regions but extends to areas that require support for strengthening initiatives to promote digital inclusivity.

In conclusion, while the presence of first-class public libraries may be more pronounced in economically robust southeast coastal provinces, library infrastructure is rapidly expanding in certain regions. Overall, these trends suggest that regions in China will take coordinated and inclusive actions to access library resources and services in a balanced manner, thereby contributing to nationwide efforts to promote digital inclusivity and literacy.

5.3. Enhancing Digital Literacy Education: Insights from a University Library Perspective

5.3.1. Fostering Digital Literacy: The Role of Academic Libraries in Modern Education

Digital literacy education holds significant importance in contemporary academia and education [56]. The rapid advancements in technology have revolutionized various aspects of our lives, including the acquisition, processing, and communication of information. In this digital age, individuals must not only possess basic computer skills but also be equipped with the ability to critically evaluate and effectively utilize digital technologies.

Academic libraries play a crucial role in promoting digital literacy education. As essential information resource centers in universities, libraries provide access to a wide range of digital academic resources and services. These resources encompass online databases, e-books, scholarly journals, and multimedia materials that enhance the research and learning experiences of students, teachers, and researchers.

Furthermore, academic libraries have recognized the necessity of actively fostering digital literacy skills among their users. They organize and offer various training programs, workshops, and online tutorials to impart essential digital skills and competencies. These initiatives help individuals develop a variety of abilities, including information retrieval and evaluation, digital communication, media literacy, and data management.

Digital literacy education provided by academic libraries extends beyond technical skills alone. It also emphasizes the development of critical thinking, problem-solving, and the ethical use of digital information. Students, teachers, and researchers are encouraged to think critically about the information they encounter online, assess its credibility, and make informed decisions.

Additionally, digital literacy education promotes inclusivity and equitable access to information. Its aim is to bridge the digital divide by equipping individuals from diverse backgrounds with the necessary skills and resources to navigate and utilize the benefits of the digital world. By promoting digital inclusion, academic libraries contribute to ensuring equal opportunities for all individuals to fully participate in academia and society.

Overall, the significance of digital literacy education cannot be overstated. It equips individuals with the necessary skills to navigate the digital landscape, enhances their academic and professional pursuits, and enables them to become informed, critical, and responsible digital citizens. Academic libraries play a vital role in this endeavor by providing digital resources and services and fostering digital literacy among students, teachers, and researchers.

5.3.2. Promoting Information Literacy: A Statistical Analysis of Participation in Chinese University Libraries, with a Focus on Wuhan University Library

The data collected from 983 university libraries in China reveals the varying levels of participation in information literacy education. The median number of participants in these programs was 3000, indicating a significant interest and engagement in information literacy activities across universities. It is important to note that the standard deviation of 8701 indicates wide variability in participation levels among different institutions.

Among these universities, Wuhan University Library stands out with the highest number of students enrolled in an information literacy education course. The library reported an impressive figure of 185,803 students participating in these courses, demonstrating a strong and active commitment to promoting information literacy among the university's student population.

This statistically significant participation in information literacy education at Wuhan University Library can be attributed to various factors. Firstly, the paper mentions that the library leverages its library science major to deliver education and training. With a rich history and broad scope, the library science major at Wuhan University is a nationally recognized first-level discipline in library information and archives management [57]. The expertise and knowledge gained through this major provide the library with inherent advantages in delivering effective information literacy education programs.

Furthermore, Wuhan University Library's commitment to information literacy is likely supported by significant resources and backing from the university itself. The university recognizes the importance of digital literacy and skills development, which may have contributed to allocating ample resources and support for information literacy education initiatives within the library.

The high participation rate in information literacy education programs at Wuhan University Library indicates a strong awareness of and response to the need for digital skills development among students. It reflects the library's dedication to empowering students with the necessary skills to navigate the digital landscape effectively and critically evaluate information sources.

Overall, the statistics on information literacy education provided in the paper convey the varying levels of participation in this domain across Chinese university libraries. Wuhan University Library's impressive numbers highlight its proactive efforts in delivering robust information literacy education programs, positioning it as a leading institution in equipping students with the digital skills needed for academic success and lifelong learning.

5.3.3. Unlocking the Advantages of Wuhan University Library: A Leading Institution for Digital Literacy Education and Training

Wuhan University Library has several inherent advantages that contribute to its effectiveness in delivering digital literacy education and training [58]:

Extensive history and experience: Wuhan University Library has a rich history that spans over a century. This long-standing experience has allowed the library to accumulate valuable knowledge and insights regarding information management and education. The library has witnessed the evolution of information technologies and has adapted its services and resources accordingly.

Vast scope and resources: Wuhan University Library encompasses a wide range of fields and disciplines. Its library science major is renowned for its comprehensive curriculum, covering various aspects of information management, library science, and archives management. This broad scope equips the library with a diverse set of resources and expertise, enabling it to offer comprehensive and multidimensional digital literacy education and training programs.

Disciplinary prowess: The library science major offered by Wuhan University is a nationally recognized first-level discipline in library information and archives management. This distinction indicates the academic rigor and disciplinary strength of the program. The library benefits from the expertise and research output of faculty members and researchers specializing in library science. Their scholarly contributions and up-to-date knowledge in the field enrich the digital literacy education programs offered by the library.

Collaborative opportunities: Being a part of Wuhan University, the library has ample opportunities for collaboration with other academic departments and institutions within the university. This collaboration facilitates interdisciplinary approaches to digital literacy education, incorporating perspectives and knowledge from various fields such as computer science, education, information technology, and social sciences. The library can tap into the expertise of these departments to design and implement innovative and tailored digital literacy programs.

Strong infrastructure and technology support: Wuhan University Library boasts a well-developed infrastructure and robust technological support. It has access to state-of-the-art digital resources, including databases, online journals, e-books, and multimedia materials. The library leverages these resources to provide hands-on training and practical learning experiences to enhance digital skills among its users. Additionally, the library invests in the latest technologies and tools to create an immersive learning environment that promotes digital literacy.

In summary, Wuhan University Library's advantages derive from its extensive history, vast scope, disciplinary prowess, collaborative opportunities, and strong infrastructure. These advantages contribute to the library's ability to deliver comprehensive and effective digital literacy education and training programs to its users.

5.3.4. Analyzing the Core Content of Wuhan University Library's Digital Literacy Training Program: Insights from TF-IDF Keyword Extraction

By utilizing the TF-IDF technique, the analysis of Wuhan University Library's training program offers significant insights into the primary content and focus of their efforts in digital literacy education and training.

The TF-IDF (term frequency–inverse document frequency) technique is widely used in information processing and data mining. It calculates the importance of a term in a collection of documents by considering its frequency within the text and its frequency throughout the entire dataset. This method is helpful for identifying keywords that have a substantial impact on the text overall while filtering out common and irrelevant words.

In this specific analysis, the extracted keywords from the library training program include the following: Database, Library, Preview, Document, Branch library, Journal, Notification, Arrangement, Music, Exploit, Lecture, Contribution, Reading, Contest, Introduction, Scientific research, Skill, Platform, Tracks, and Academic search.

These keywords offer a glimpse into the primary content and themes encompassed by Wuhan University Library's digital literacy education and training. For example:

Database: This keyword suggests that the training program covers topics related to database usage, management, and information retrieval. It indicates a focus on developing skills for navigating various databases for academic research purposes.

Library: The inclusion of the keyword "Library" signifies that the training program emphasizes the utilization of library resources and services. It may involve instructions on how to effectively search for and access scholarly materials, e-books, journals, and other digital resources available through the library.

Preview and Document: These keywords suggest that the program covers aspects related to document handling, digital document formats, and techniques for previewing and navigating digital documents. This indicates a focus on developing skills in document management and utilization in the digital environment.

Branch library and Journal: The presence of these keywords suggests that the program may include training on utilizing branch libraries and accessing specific journal databases for scholarly research. It highlights the resources and services available beyond the main library and the importance of staying up-to-date with the latest research in different academic disciplines.

Skills and Platform: The inclusion of these keywords implies that the training program aims to enhance students' proficiency in digital skills. It may cover various digital tools, software platforms, and online resources that are essential for academic research and digital literacy.

Overall, the analysis of the keywords from the library training program provides valuable insights into the key areas of focus in digital literacy education and training offered by Wuhan University Library. It reveals a comprehensive approach that encompasses database usage, library resources, document management, research skills, and the utilization of digital platforms. These insights can contribute to a better understanding of the specific aspects of digital literacy training provided by the library, thereby forming the basis for further discussions and improvements in the program.

5.3.5. Promoting Digital Inclusion and Equitable Access: The Role of Academic Libraries in Integrated Public Information Services

Digital inclusion aims to provide equal access to and usage of digital technologies and the internet for all individuals, regardless of their socioeconomic background or physical abilities. It goes beyond simply providing hardware and connectivity; it also encompasses digital literacy skills, relevant content, and the ability to fully participate in the digital society.

Academic libraries play a crucial role in promoting digital inclusion by offering public information services to their diverse user groups, including students, faculty, researchers, and the wider community. These libraries are commonly regarded as information resource centers within universities, providing various resources and services to support teaching, learning, and research activities.

To ensure fair access to digital information and knowledge, academic libraries are integrating digital inclusion into their services and programs [59–61]. This integration involves several key aspects:

Broadening access: Academic libraries are implementing initiatives to expand access to digital resources, such as e-books, e-journals, databases, and other online materials. They are also enhancing access to digital services, including online reference assistance, digital interlibrary loans, and remote access to library resources. By making these resources and services available online, libraries are removing barriers to information access and reaching a wider user base.

Digital literacy education: Academic libraries are taking on the important task of fostering digital literacy skills among their users. They offer a range of training programs, workshops, and tutorials to enhance digital skills, such as information searching, digital content evaluation, data management, and digital ethics. These initiatives aim to empower users with the knowledge and skills required to navigate the digital landscape effectively and critically.

Inclusive design and assistive technologies: Academic libraries are ensuring that their digital resources and services are designed inclusively, taking into account the diverse needs and abilities of their users. They are adopting accessible web design practices, providing assistive technologies, and offering specialized services for users with disabilities. These efforts aim to remove barriers for individuals with different abilities and ensure their full participation in accessing and utilizing digital information.

Collaborations and partnerships: Academic libraries are actively collaborating with other institutions, organizations, and community groups to enhance digital inclusion. They form partnerships with local community centers, schools, and public libraries to extend their services beyond the university campus. By working together, they can leverage resources, share expertise, and collectively address the challenges of digital exclusion in their communities.

Overall, the integration of digital inclusion into the public information services of academic libraries demonstrates their commitment to ensuring equitable access to digital information and knowledge. By broadening access, providing digital literacy education, adopting inclusive design practices, and fostering collaborations, these libraries are striving towards a more inclusive, digitally empowered, and sustainable society.

6. Conclusions and Recommendations

This study has provided valuable insights into the state of digital inclusion and digital literacy education in Chinese libraries, identifying challenges and disparities across regions and demographic groups, as well as limitations and barriers faced by libraries in promoting digital inclusion. Based on these findings, the following recommendations are proposed for future research and practice in library science and policy-making:

6.1. Strengthen Policy Coordination and Interdepartmental Collaboration

Policymakers should foster better cooperation and coordination among the different government agencies responsible for digital inclusion and digital literacy initiatives [62].

Promote information sharing and collaboration among government agencies, non-governmental organizations, educational institutions, and industry partners through the establishment of digital platforms or networks.

Emphasize policy coherence and synergies with regular interdepartmental meetings, policy reviews, and joint workshops to ensure consistent and effective implementation of digital inclusion and digital literacy policies.

Encourage public participation through consultations, surveys, or focus groups to gather feedback and address the needs and aspirations of the target population.

6.2. Expand Local-Level Initiatives for Digital Inclusion and Digital Literacy

Extend digital inclusion and digital literacy initiatives to all regions, particularly economically underdeveloped and rural areas.

Give special attention to these areas, allocating additional resources and support for infrastructure development, internet connectivity, and access to digital learning centers.

Increase investment and support in digital inclusion and digital literacy by local governments, including the construction and maintenance of digital learning centers and widespread internet access in local communities.

Establish digital learning centers in underserved areas, providing access to computers, internet connectivity, and tailored training programs.

Improve internet access in rural areas through infrastructure development and government subsidies.

6.3. Enhance Digital Services in Public Libraries

Focus on expanding digital resources in public libraries by acquiring a broader range of digital content and investing in platforms and technologies that facilitate the borrowing and lending of digital materials [63,64].

Adopt innovative approaches to deliver digital services, such as virtual reality, augmented reality, and virtual assistants, to enhance the user experience.

Prioritize digital literacy education with workshops, training programs, and resources covering various aspects of digital skills and knowledge.

Pursue collaboration with local educational institutions, community organizations, and technology experts to develop comprehensive and targeted digital literacy programs.

Conduct continuous evaluation and updating of digital services and digital literacy programs based on user feedback and emerging trends.

6.4. Expand Digital Literacy Education in Academic Libraries

Focus on expanding digital resources, including e-books, e-journals, databases, and other online materials, to support the academic pursuits of students, faculty, and researchers [65–67].

Implement comprehensive and engaging digital literacy education programs covering information retrieval, data management, digital ethics, online collaboration, and critical evaluation of digital content.

Encourage collaboration with academic departments to integrate digital literacy skills into the curriculum and develop specialized programs and resources.

Utilize innovative technologies and digital tools to enhance the learning experience and promote digital literacy.

Conduct regular assessments and evaluations of digital literacy programs to ensure their effectiveness and identify areas for improvement.

6.5. Promote Digital Inclusion and Ensure Equitable Access

Strive to broaden the avenues through which users can access digital resources in public libraries, including user-friendly websites and alternative access points in underserved areas [52,62,68].

Provide digital literacy education to empower users with the necessary skills to navigate the digital landscape effectively.

Adopt inclusive design practices to ensure accessibility for individuals with disabilities or specific needs.

Strengthen collaboration among community centers, schools, and public libraries to jointly promote digital inclusion and digital literacy education.

In conclusion, digital inclusion and digital literacy are crucial for active participation in a digital society. Chinese libraries can play a significant role in achieving these goals through policy coordination, local-level initiatives, enhanced digital services, expanded digital literacy education, and promoting equitable access. It is recommended that policymakers provide the necessary resources and support to libraries to effectively fulfill their role in promoting digital inclusion and digital literacy education. By implementing these recommendations, libraries can contribute to a more inclusive, equitable, and sustainable society in the digital age.

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Article

TPACK's Roles in Predicting Technology Integration during Teaching Practicum: Structural Equation Modeling

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Abstract: The current study aims to report the role of technological pedagogical and content knowledge (TPACK) in the integration of technology by preservice teachers during teaching practicum. As this study employed a survey as its methodological approach, instruments measuring TPACK and the integration of technology during teaching practicum were developed based on prior studies and validated through content validity and a pilot study. The main data (n. 1333) were analyzed through the partial least squares structural equation model (PLS-SEM), supported by importance performance map analysis (IPMA). The study's results were satisfactory in determining the scale's validity and reliability. The structural model shows that all the hypothetical interactions were positively significant. The strongest relationship between the TPACK factors emerged between technological pedagogical knowledge (TPK) and TPACK. Additionally, technology integration was most significantly affected by TPACK.

Keywords: preservice teachers; teaching practicum; technology integration; TPACK

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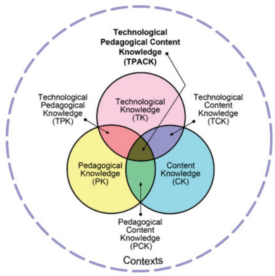
1. Introduction

Technological pedagogical and content knowledge (TPACK) combines the basic dynamics of teaching with the use of technology [1], that has been used to evaluate teachers' integration of technology into their practice [2,3]. It was was founded on Shulman's principle, PCK [4], which is primarily concerned with developing the most appropriate teaching methods. The debate was focused on the historical improvement in the quality of education, which suggested that content and pedagogy should be seen as one indistinguishable body of knowledge. Considering the importance of the PCK concept, TPACK was developed as a mechanism for defining the components of the successful integration of technology in educational activities [4]. Within this context, teachers must conceptualize the relationships between technology, pedagogy, and content factors to integrate technology effectively and efficiently [5]. Technological pedagogical and content knowledge comprises seven factors: TK, PK, CK, TPK, TCK, PCK, and TPACK (Figure 1).

Prior studies assessed the role of TPACK in predicting teachers' use of technology in education [6–8]. These studies employ the role of TPACK in predicting the integration of technology during teaching through direct relationships. Limited studies explored the indirect relationships among the factors, especially in the context of developing countries. Therefore, this research aims to report the interconnection between TPACK factors and the role of TPACK in the integration of technology during teaching practicum, including its indirect effects. To support the relationship assessment, the scale for the study was validated and assessed for its reliability. Three research questions are proposed as the objectives of the study:

1. Is the scale proposed for the model valid and reliable?
2. What are relationships between the TPACK factors during teaching practicum?

3. What is the direct relationship between four TPACK components (TCK, PCK, TPK, TPACK) and the integration of technology during teaching practicum?
4. To what extent does TPACK mediate the relationship between three components (TCK, PCK, and TCK) and the integration of technology?



- TK (knowledge of how to use different technologies)
- PK (knowledge of different teaching and learning approaches and theories of learning)
- CK (knowledge of subject matter)
- TPK (knowledge of how teaching and learning might change because of the usage of specific technology in specific ways)
- TCK (knowledge of how technology and content interact to impact and restrict one another)
- PCK (knowledge of how to combine the CK and PK to make the content understandable)
- TPACK (knowledge of how to combine different knowledges, how to use appropriate pedagogical approaches for certain content with appropriate technology)

Figure 1. The TPACK conceptual model and definitions; TPACK figure is rights-free; retrieved from http://tpack.org (accessed on 1 August 2022).

2. Literature Review

2.1. TPACK Scale Reliability and Validity

The first documented and, probably, the most frequently cited TPACK scale was proposed by Schmidt et al. [9] to assess preservice teachers in the USA. The instrument's validity using Cronbach's alpha and construct validity resulted in seven factors: TK, PK, CK, PCK, TCK, TPK, and TPACK. The authors proposed a pool of 47 indicators in the first process of establishment. The study's remaining indicators resulted in 45 items, most of which were modified, and a few of which were deleted. Some researchers using Schmidt et al.'s [9] instrument failed to prove all the seven factors of knowledge when they validated the adaptations in different contexts and settings [10–16]. For example, Luik et al. [14] reported three valid factors, technology, pedagogy, and content, in the context of Estonian preservice teachers, while Chai et al. [12] reported eight factors. The instrument should always be validated and examined for its reliability, which we also addressed in this study.

2.2. TPACK Factors' Inter-Correlation and Their Relations with the Integration of Technology

Prior studies examined the inter-correlations among TPACK components (Table 1). For instance, Dong et al. [17] surveyed 390 preservice teachers and 394 in-service teachers regarding the seven factors of TPACK. They reported the inter-correlation among these TPACK constructs; most of the correlational relationships were found to be significant, namely those between CK and TCK, CK and TPACK, TK and TCK, PK and PCK, PK and TPK, and TPK and TPACK. Furthermore, four TPACK components' correlations were considered insignificant: PCK and TPACK, CK and PCK, TK and TPACK, and PK and TPACK. In addition, Wu et al. [18] reported that all the relationships between TPACK factors were significantly perceived by 211 school teachers in China. Pamuk et al. [19] mentioned some significance relationships among the following factors: TK and TPK, TK and TCK, PK and TPK, PK and PCK, CK and PCK, CK and TCK, TCK and TPACK, TPK and TPACK, and PCK and TPACK. Three correlations were insignificant: those between CK and TPACK, PK and TPACK, and TK and TPACK. Although many studies have reported valid instruments assessing TPACK factors, more studies should be conducted; the findings could be used to either refine or critique the prior instruments.

Table 1. TPACK-factors-intercorrelation studies.

Author	n. Sample	Method	Inter-Correlation
[18]	211 school teachers	Pearson product-moment correlations (r)	PK -> CK (r = 0.63) ** CK -> PCK (r = 0.42) ** CK -> TK (r = 0.29) ** TK -> TPCK (r = 0.56) ** PCK -> TPK (r = 0.54) ** TCK -> PCK (r = 0.43) ** TPK -> TPCK (r = 0.73) ** TPCK -> CK (r = 0.27) ** etc.
[17]	390 PSTs 394 in-service teachers	CB-SEM	CK -> TCK (β = 0.13) ** CK -> TPACK (β = 0.10) * TK -> TCK (β = 0.63) ** TK -> TPK (β = 0.46) ** PK -> PCK (β = 0.64) ** PK -> TPK (β = 0.35) ** TPK -> TPACK (β = 0.31) **
[19]	177 Turkish PSTs (1st phase) 882 Turkish PSTs (2nd phase)	Path analysis (CB-SEM)	TK -> TPK (β = 0.74) ** TK -> TCK (β = 0.62) ** PK -> TPK (β = 0.28) ** PK -> PCK (β = 0.70) ** CK -> PCK (β = 0.34) ** CK -> TCK (β = 0.19) ** TCK -> TPACK (β = 0.58) ** TPK -> TPACK (β = 0.41) ** PCK -> TPACK (β = 0.16) **
[20]	665 PSTs in 18 Belgium training institutions	Factor correlation	TPK -> TCK (0.98) ** TPK -> TPACK (0.99) ** TCK -> TPACK (0.98) ** TK -> TPK (0.86) ** TK -> TPK (0.81) ** TK -> TPCK (0.81) **
[16]	276 PSTs from Finland	Pearson product-moment correlations (r)	PK21 -> PCK21 (r = 0.74) ** CK -> PCK 21 (r = 0.47) ** CK -> TK (r = 0.25) ** PCK21 -> TK (r = 0.21) ** TCK -> PK21 (r = 0.62) ** TK -> PK21 (r = 0.22) ** TPK21 -> PK21 (r = 0.51) TCK -> TK (r =0.44) ** TPK21 -> TCK (r = 0.72) ** TPK21 -> PCK21 (r = 0.62) ** TCK -> PCK21 (r = 0.62) ** etc.
[21]	287 preservice language teachers	PLS-SEM	TK -> TCK (β = 0.321) ** TK -> TPK (β = 0.286) ** CK -> TCK (β = 0.281) ** CK -> PCK (β = 0.224) ** PK -> TPK (β = 0.377) ** PK -> PCK (β = 0.447) ** TCK -> TPACK (β = 0.144) ** TPK -> TPACK (β = 0.555) ** PCK -> TPACK (β = 0.199) **
[22]	481 Indonesian PSTs	Pearson product-moment correlations (r)	TK -> CK (r = 0.51) ** CK -> PCK (r = 0.69) ** TK -> TPK (r = 0.59) ** PCK -> TPK (r = 0.74) ** PK -> TPK (r = 0.65) ** TPK -> TPACK (r = 0.89) ** etc.

Note. * $p < 0.05$; ** $p < 0.01$.

Studies have revealed the relationship between TPACK factors and the integration of technology (Table 2), such as between PK and the integration of ICT [23], TPK and the integration of technology [24], TPACK and the intention to use technology [6–8], perceived

PK and the perception of the integration of technology [25], TPACK and the integration of technology [26], as well as digital nativity and TPACK [27]. However, these studies explored TPACK's partial components. Within this study context, a complex relationship between all the TPACK components or factors and the integration of technology would lead to a comprehensive academic reference for future research. Reports on the systematic interconnection between the factors of TPACK and their connections with technology integration are still limited, especially in developing countries.

Table 2. The correlations between TPACK and technology integration in education.

Author	Sample	Method	Significant Correlation
[28]	349 in-service high-school teachers in Turkey	SEM	TPACK -> Technostress (β = −0.240) *
[21]	287 preservice language teachers	PLS-SEM	TPK -> use of ICT (β = 0.153) **, PCK -> TPACK (β = 0.199) **, PCK -> use of ICT (β = 0.092) **, TPACK -> use of ICT (β = 0.354) **
[29]	209 Iranian EFL teachers	CB-SEM	TPACK -> Technology integration (β = 0.262) *
[30]	Two preservice teachers	Regression	TPACK -> Behavioral intention attitude to ICT (β = 0.560) **
[23]	599 Turkish PSTs from 6 universities	CB-SEM	PK -> Integration of ICT * (β = 0.330) **
[31]	1181 PSTs	PLS-SEM	TPACK -> Behavioral intention (β = 0.235) **
[6]	296 Koran PSTs	CB-SEM	TPACK -> intention to use ICT (β = 0.560) **
[25]	54 teacher educators	CB-SEM	Perceived PK -> Perceived technology integration (β = 0.18) ** Perceived TK -> perceived technology integration (β = 0.720) **
[7]	226 Serbian PSTs	CB-SEM	TPCK -> Behavioral intention, traditional use of technology (β = 0.30) ** TPCK -> Behavioral intention, innovative use of technology (β = 0.33) **
[8]	464 Chinese PSTs	CB-SEM	TPACK -> intention to use Web 2.0 technology (β = 0.260) **
[26]	688 PSTs	SEM	TPACK -> Technology integration (r = 0.12) **
[27]	1439 Turkish PSTs	CB-SEM	Digital nativity -> TPACK (β = 0.59) **

Note. * $p < 0.05$; ** $p < 0.01$.

From the perspectives of preservice teachers, the main goal of this study was to explain the relationships between TPACK components and between TPACK and technology integration. Sixteen hypotheses, which included the seven TPACK factors and technology integration, were proposed for the conceptual model of this study; thirteen hypotheses were related to direct relationships (e.g., TK has a significant relationship with TCK, H1). In addition to these direct relationships, we included three indirect relationships that connect TPC, TCK, and PCK to technology integration through TPACK (e.g., TCK has a significant relationship with technology integration through TPACK, H13). All the hypotheses are exhibited in Figure 2.

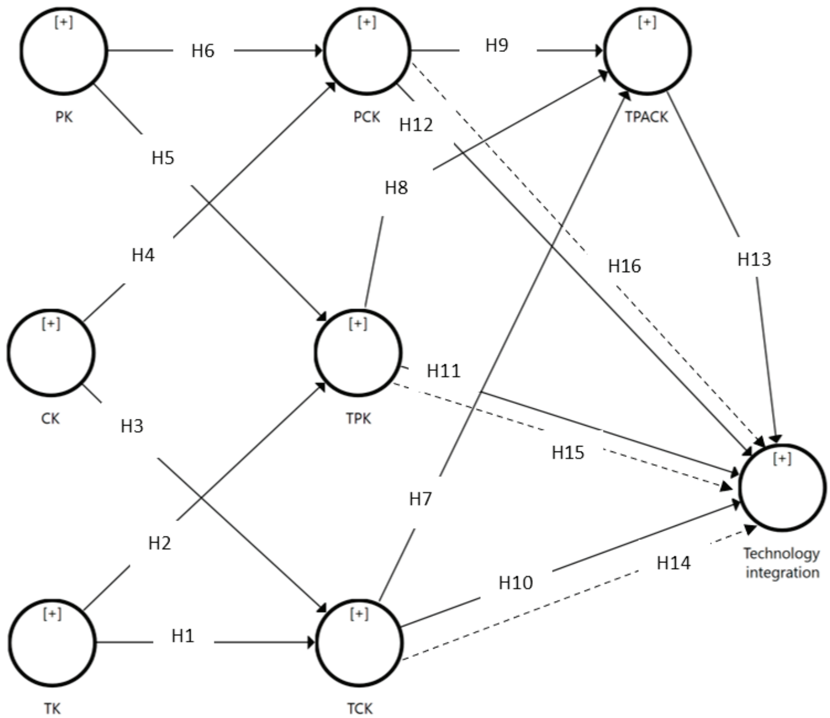


Figure 2. A proposed model that elaborates on intercorrelations within TPACK and correlations between TPACK's knowledge combination and technology integration among Indonesian preservice teachers (direct effects, ⟶; indirect effects, ⇢).

3. Methods

3.1. Instrumentation

Since the concept of data propagation does not hamper the research method, we applied a predictive strategy to approximate the causality concept. Before the data collection, prior research was reviewed to evaluate the instrument's validity and reliability. The study of the literature assists researchers in defining and analyzing the ideas and principles that establish the research's theoretical context and determine suitable tools and instruments to use to achieve the research's goals; we adapted prior valid instruments for this study (n. items = 44): TPACK [9,13,14] and technology integration ICT [23]. Five users (three preservice teachers, a staff member, and a lecturer) discussed the instruments for face validity. Five educational-technology and -policy experts were also invited to discuss the instruments for the content-validity process. We removed 6 items, leaving 38 items to be piloted. The instruments were evaluated using exploratory factor analysis (EFA) with the following criteria: Sphericity Bartlett Test ($p < 0.500$), Kaiser–Meyer–Olkin (>0.800), Factor Loading (0.500), Communalities ($\geq$0.300), and Eigenvalue (>1.00), which resulted in eight different variables. Two hundred and eighty-seven preservice teachers participated in the pilot study of the survey instruments. All measurement values met the threshold. However, two indicators from TPACK were removed due to cross-loading detection in the EFA.

3.2. Data Collection

The target population covered all preservice teachers in three Indonesian universities. Through stratified sampling [32], the instruments were distributed. From the distribution of 1350 questionnaires, 127 respondents (9.41%) did not return a questionnaire, resulting in 1223 returned data. Hence, the outliers and missing data (90, or 6.67%) were deleted, which resulted in 1133 usable responses. Nine hundred and twenty-three respondents were females, while two hundred and ten were males. The number of respondents for each age range was as follows: 18 to 19, 15 respondents; 20 to 21, 935; and >21, 183. University A provided 631 respondents, University B provided 378, and University C provided 124. University A is an Indonesian public university that runs pre-service-teacher-training programs with more than 1200 PSTs; University B is also a public university, with almost 1000 PSTs; and University C is a private university with fewer than 300 PSTs. Regarding the participants' majors, 217 respondents were from social science education, 457 respondents were from science education, 289 respondents were from language education, and 170 respondents were from preschool- and primary-teacher education. Similarly, respondents' participation in ICT-based courses also varied; 1 course (455 respondents), 2–3 courses (500 respondents), and more than three courses (178 respondents).

3.3. Analysis and Findings

Skewness and kurtosis computations were conducted for the normality test. Skewness tests the evidence of skewed variable data distribution (towards the distribution's left or right tail). Values greater than +1 or lower than −1 indicate that the data are substantial. Kurtosis is the extent to which data measure whether the distribution is too peaked, with a narrow distribution, and with most responses in the central part. The recommended kurtosis value is between −2 and +2 for the normal data [33,34]. The skewness and kurtosis for the TPACK factors and technology integration were satisfactory. The skewness values for the TPACK ranged from −0.252 (PCK) to 0.170 (TPACK); the kurtosis values ranged from −0.144 (PK) to 1.393 (PCK). Furthermore, the skewness and kurtosis for technology integration were −0.129 and 0.667, respectively, meeting the cut-off values.

4. Measurement Model

The loadings in the measurement model contributed significantly to their respective variables, as seen in Figure 3. The indicators that were loaded above 0.5 were held when the average variance extracted (AVE), rho_A, and composite stability (CR) exceeded their suggested values, respectively [35]. Table 3 shows that the AVE values of the model ranged between 0.5070 and 0.9010, indicating a good convergence validity. Similarly, the values of rho_A and CR (>0.700) demonstrated the constructs' reliability and internal consistency [36]. To avoid any issues of multicollinearity, the VIF values were computed. The VIF values reported in Table 3 suggest that the data were free of multicollinearity issues. Furthermore, the heterotrait–monotrait ratio (HTMT) examination for values below 0.900 was reported for the assessment of discriminant validity; this is the most robust criterion for discriminant validity for PLS-SEM procedures [37,38]. The HTMT values differed and were below 0.900, affirming the discriminant validity (Table 4). In this study, standardized root mean squared residual (SRMR) was used to assess the model fit. The SRMR is the only proper model fit implemented for PLS-SEM [38]. In addition, dG and dULS were also recommended for the model fit; they are defined as distance measures that connect in more than one way when quantifying discrepancies between matrices [38]. Both values are presented in Table 2 (1.961 and 0.65), reflecting the quality of the model. Furthermore, the SRMR value of 0.054 was lower than the threshold of 0.08, which validates the model's overall value [38].

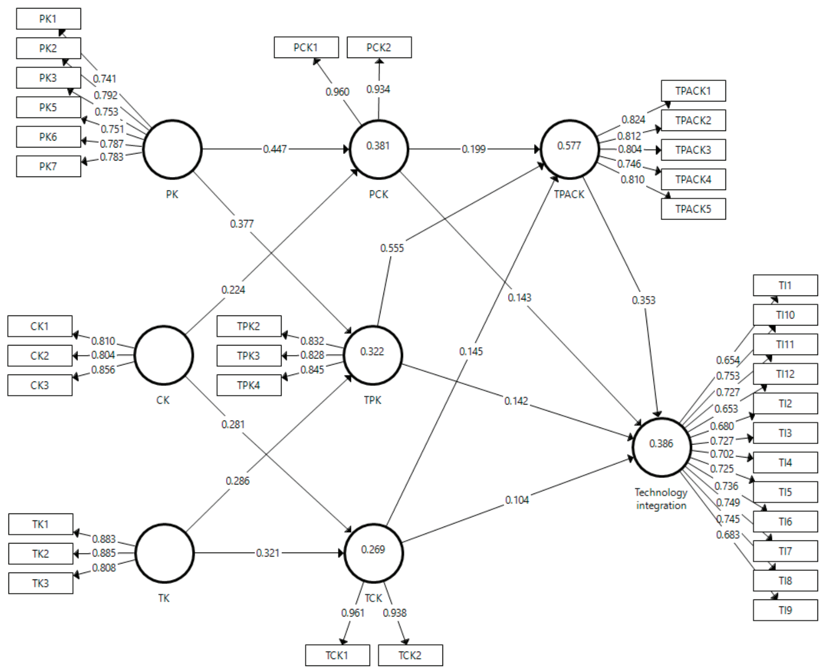


Figure 3. Measurement model showing the substantial loading of the scale of the construct.

Table 3. Factor loading, reliability, and validity of measurement model.

Construct	Items	Loading	rho_A	CR	AVE	VIF
CK	CK1	0.8100	0.7680	0.8640	0.6790	1.448
	CK2	0.8040				1.577
	CK3	0.8560				1.704
PCK	PCK1	0.9600	0.9240	0.9460	0.8970	2.737
	PCK2	0.9340				2.737
PK	PK1	0.7410	0.8620	0.8960	0.5900	1.687
	PK2	0.7920				1.921
	PK3	0.7530				1.692
	PK5	0.7510				1.726
	PK6	0.7870				1.859
	PK7	0.7830				1.866
TCK	TCK1	0.9610	0.9240	0.9480	0.9010	2.832
	TCK2	0.9380				2.832
Technology integration	TI1	0.6540	0.9130	0.9250	0.5070	1.791
	TI10	0.7530				2.232
	TI11	0.7270				2.134
	TI12	0.6530				1.753
	TI2	0.6800				1.687
	TI3	0.7270				2.243
	TI4	0.7020				1.985
	TI5	0.7250				2.267
	TI6	0.7360				2.463
	TI7	0.7490				2.201
	TI8	0.7450				2.231
	TI9	0.6830				1.801

Table 3. *Cont.*

Construct	Items	Loading	rho_A	CR	AVE	VIF
TK	TK1	0.8830	0.8330	0.8940	0.7380	2.024
	TK2	0.8850				2.218
	TK3	0.8080				1.615
TPACK	TPACK1	0.8240	0.8620	0.8990	0.6400	1.974
	TPACK2	0.8120				1.942
	TPACK3	0.8040				1.916
	TPACK4	0.7460				1.624
	TPACK5	0.8100				1.902
TPK	TPK2	0.8320	0.7850	0.8740	0.6970	1.635
	TPK3	0.8280				1.623
	TPK4	0.8450				1.629

Table 4. HTMT < 0.900 and model fit [37].

	CK	PCK	PK	TCK	TK	TPACK	TPK	Saturated Model	
PCK	0.6180							SRMR	0.054
PK	0.8000	0.6700						d_ULS	1.961
TCK	0.5200	0.5020	0.5060					d_G	0.65
TK	0.6090	0.4390	0.5390	0.5240					
TPACK	0.6680	0.5650	0.6960	0.6090	0.5830				
TPK	0.6020	0.5040	0.6150	0.6570	0.5680	0.8740			
Technology integration	0.5300	0.4670	0.5830	0.4760	0.5240	0.6530	0.6050		

5. Structural Model

The data were bootstrapped with 5000 subsamples to investigate the link between the exogenous and endogenous factors. All the hypotheses were significant; we used a 5% significance threshold (Table 3 and Figure 3). The results support H1 and H2; TK is a significant predictor of TCK (β = 0.3210; t = 9.1850) and TPK (β = 0.2860; t = 0.85160). The TCK and PCK are also significantly predicted by CK, supporting H3 and H4. Similarly, H5 and H6 were also positively confirmed, and PK had significant relationships with TPK (β = 0.3770; t = 12.1920) and PCK (β = 0.4470; t = 13.2060). The TCK was a significant predictor of TPACK and technology integration, supporting H7 (β = 0.1450; t = 5.8940) and H10 (β = 0.1040; t = 3.3340), respectively. The TPK in this study had a significant relationship with TPACK and technology integration (β = 0.5550; t = 23.5870 and β = 0.1420; t = 3.6830), supporting H8 and H11. In addition, H9 and H12 were also confirmed; the SmartPLS 3.3 results showed a *p*-value of <0.001, suggesting significant relationships between PCK, TPACK (β = 0.1990; t = 7.7540), and technology integration (β = 0.11430; t = 4.6040). Regarding the indirect hypotheses (H14, H15, and H16) and the mediating role of TPACK in the effects of TCK, TPK, and PCK on technology integration, the present study reports that TCK has an indirect positive effect on technology integration, which is mediated by TPACK (β = 0.0510; t = 5.1570), H14. Furthermore, TCK also positively predicted technology integration through TPACK (β = 0.1960; t = 8.4260); this result supports H15. Finally, technology integration was also significantly predicted by PCK through TPACK (β = 0.0700; t = 5.6610).

When a particular exogenous variable is removed from the model, the f^2 effect size is used to investigate the change in R^2 values. According to the PLS-SEM guidelines, an f^2 value of 0.02 indicates a small impact, 0.15 indicates a medium impact, and 0.35 indicates a large impact. The effect sizes of the endogenous factors were addressed by all the exogenous factors (Table 5). The largest effect emerged in the relationship between TPK and TPACK (0.4770), while the smallest effect resulted from the relationship between TPK and technology integration (0.0150). The coefficient of determination (R^2) is a number that indicates how accurate a prediction is, calculated as the squared correlation between two dependent variables. For the range of 0 to 1, the R^2 value is counted. A greater R^2 number suggests a better level of predictability. An R^2 score of 0.25 is deemed weak, a value of 0.50 is considered moderate, and a value of 0.75 is strong. From the data computation, all the endogenous variables of the model achieved proper levels of predictive accuracy. The R^2 value of the TCK was 0.2690 (weak), that of the TPK was 0.3220 (moderate), that of the PCK was 0.3810 (moderate), that of the TPACK was 0.5770 (moderate), and that of technology integration was 0.3860 (moderate) (Figure 3). A Q^2 score greater than zero implies that a model's predictive relevance has been attained. The predictive relevance levels are 0.02 (low), 0.15 (mid), and 0.35 (large) [37,38]. In the SmartPLS, blindfolding computation was used to address the predictive relevance. All the Q^2 values were greater than 0, indicating that they were predictive. The Q^2 results in Figure 4 support the model's predictive relevance for all the following endogenous variables: TCK (0.2350, mid), TPK (0.2220, mid), PCK (0.3330, large), TPACK (0.3640, large), and technology integration (0.1910, mid).

Table 5. Structural model, TPACK factors' intercorrelation and correlation with technology integration.

H	Coefficient	β	*t*-Value	*p*-Value	f^2	Remarks
H1	TK -> TCK	0.3210	9.1850	$p < 0.001$	0.1080, medium	Supported
H2	TK -> TPK	0.2860	8.5160	$p < 0.001$	0.0960, medium	Supported
H3	CK -> TCK	0.2810	8.3310	$p < 0.001$	0.0830, small	Supported
H4	CK -> PCK	0.2240	6.1870	$p < 0.001$	0.0470, small	Supported
H5	PK -> TPK	0.3770	12.1920	$p < 0.001$	0.1660, medium	Supported
H6	PK -> PCK	0.4470	13.2060	$p < 0.001$	0.1860, medium	Supported
H7	TCK -> TPACK	0.1450	5.8940	$p < 0.001$	0.0310, small	Supported
H8	TPK -> TPACK	0.5550	23.5870	$p < 0.001$	0.4770, large	Supported
H9	PCK -> TPACK	0.1990	7.7540	$p < 0.001$	0.0700, medium	Supported
H10	TCK -> Technology integration	0.1040	3.3340	$p < 0.01$	0.0110, small	Supported
H11	TPK -> Technology integration	0.1420	3.8630	$p < 0.001$	0.0150, small	Supported
H12	PCK -> Technology integration	0.1430	4.6040	$p < 0.001$	0.0230, small	Supported
H13	TPACK -> Technology integration	0.3530	9.2400	$p < 0.001$	0.0860, medium	Supported
H14	TCK -> TPACK -> Technology integration	0.0510	5.1570	$p < 0.001$	-	Supported
H15	TPK -> TPACK -> Technology integration	0.1960	8.4260	$p < 0.001$	-	Supported
H16	PCK -> TPACK -> Technology integration	0.0700	5.6610	$p < 0.001$	-	Supported

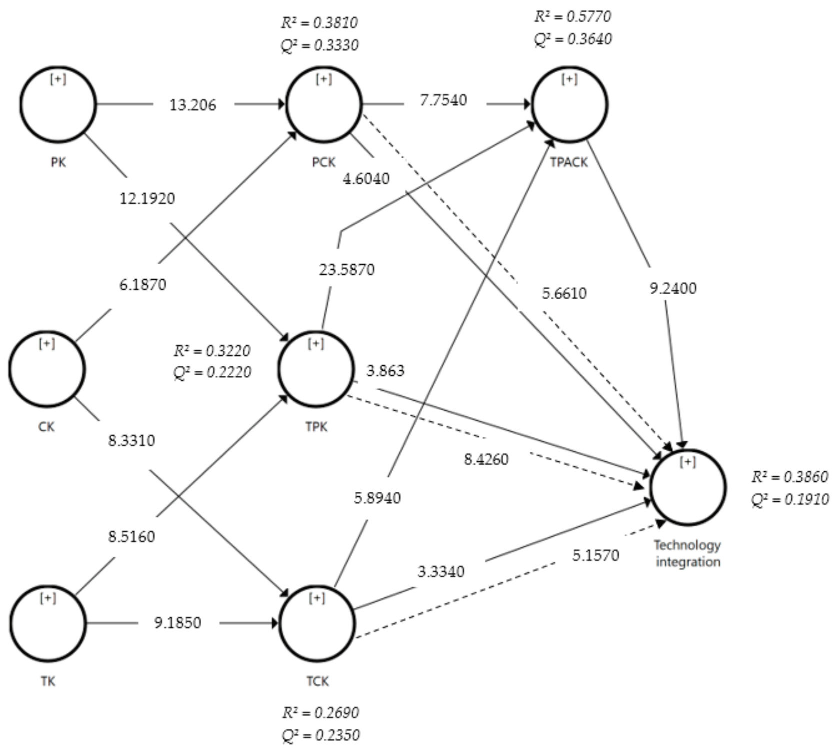


Figure 4. The *t* value, coefficient of determination (R^2), and predictive relevance (Q^2) of the final model.

6. Importance of Performance Map Analysis (IPMA)

The goal of IPMA is to understand the impact of an independent variable's overall unstandardized influence on the anticipation of a specific dependent variable. The IPMA is divided into significance and performance [39,40]. The components in this study were categorized based on their overall effects on performance and importance ratings. Before usage, the outer weights must be positive values, and all the indicators must have similar directions [41]. Higher coefficient values produce greater importance. The TCK had a high direct positive importance through the CK (0.3090) and TK (0.3260). The PK (0.4120) had a higher positive importance for the TPK than for the TK (0.2570). The PK (0.5540) demonstrated a significantly more positive importance for the PCK than for the CK (0.2470). The lowest exogenous variable regarding the TPACK's importance effect was PCK (0.1670), while the greatest effect was demonstrated by TPK (0.5290). The TPACK (0.3590) had the strongest impact on technology integration, while the lowest impact was TCK on technology integration (0.1330).

In addition, high performance values emerging for a construct (1–100) indicate the higher performance of that construct [39,40]. The IPMA computation in the SmartPLS shows that technology integration (70.4130) demonstrated the highest performance, while the lowest performance was presented by the TPK (62.0710). The details of the performances of all the constructs are shown in Table 6. If educational stakeholders aim to improve the TPACK program in higher-education and technology integration for preservice teachers, their focus should be on all the constructs due to their high importance and performance.

Table 6. IPMA results.

	Importance and # (Rank)					Performance
	TCK	TPK	PCK	TPACK	Technology Integration	
CK	0.3090, #2		0.2470, #2			66.5700
PCK				0.1670, #2	0.1830, #3	66.6570
PK		0.4120, #1	0.5540, #1			67.4310
TCK				0.1220, #3	0.1330, #4	67.4200
TK	0.3260, #1	0.2570, #2				62.4450
TPACK					0.3590, #1	65.2350
TPK				0.5290, #1	0.3280, #2	62.0710
Technology integration						70.4130

7. Discussion

The instrument was distributed to 287 preservice teachers for a pilot study; we conducted EFA and reliability tests to purify the instrument measuring TPACK and technological integration. As recommended, the measurement-model process was conducted, informing reflective indicator loadings, internal consistency reliability, and convergent and discriminant validity [37]. The purification procedures were also suggested and conducted in other settings and contexts regarding TPACK and the integration of technology [7,8,25,26,41]. Thirty-six indicators were valid and reliable within the proposed mode, which confirmed the first research question (RQ1) of the current study.

The Intercorrelations between the TPACK factors for RQ2 were positively significant [12]. From the structural model assessment and IPMA, TPK had the highest importance level in predicting TPACK, followed by PCK and TCK. Furthermore, PK was the TPK and PCK's key predictor, with the strongest performance. The TCK, on the other hand, was mostly predicted by TK, with 0.3260 of the importance levels compared to 0.3090, resulting from the effect of CK's importance on TCK. Some of the associations were similar to those discovered in previous studies. Dong et al. [17] and Scherer et al. [20] found similar results; TPK was the most significant predictor of TPACK. Meanwhile, Pamuk et al., [19] reported TCK as the most significant predictor of TPACK; all the intercorrelations between the TPACK constructs were significant. The only prior study that contradicted the significance of this study's TPACK intercorrelations was reported by Chai et al. [12]; TPACK was found not to be significantly correlated with TPK, TCK, and PCK.

The main goal of this study was to understand the roles of the combined knowledge of technology, pedagogy, and content (TCK, TPK, PCK, and TPACK) in predicting the integration of technology among Indonesian preservice teachers [21]. A few studies have been conducted regarding the relationships between all the TPACK factors and technology integration. Through the structural model assessment, all the hypotheses regarding the relationships between the TPACK factors and technology integration were positively confirmed. Technological pedagogical and content knowledge is the strongest predictor of technology integration during teaching practicum, followed by PCK, TPK, and TCK. Through IPMA, the results were slightly different; TPACK had the highest level of importance for technology integration, followed by TPK (not PCK). This discrepancy might have been caused by the role of TPACK in mediating the indirect correlations between TCK, TPK, PCK, and technology integration. These indirect relationships are also significant, suggesting that TPK is the strongest predictor of technology integration mediated by TPACK. These findings strengthen those of prior studies regarding the relationship between TPACK and technology integration, confirming the roles of TPACK factors (direct or mediated) in technology integration for RQ3 and RQ4 [28–30].

8. Conclusions

This study's core contribution is the clarification of the roles of TPACK in technology integration during teaching practicum, as perceived by Indonesian preservice teachers. Before defining the role of TPACK in the integration of technology, the connectivity of TPACK factors was investigated. A deeper understanding of preservice teachers' opinions of TPACK can improve program efficiency regarding the integration of technology by preservice teachers. One of the main goals of teacher-education programs is to assist preservice teachers in developing their understanding of the modern educational system's demand for the integration of technology into the classroom. In addition, various methodological limitations should be addressed when interpreting the current study's findings. This study developed a combination of technology models that consider TPACK factors, which explained the integration of technology in teaching practices. Thus, theoretical and empirical evidence is offered to all stakeholders to improve Indonesian PSTs and training programs' performance by informing the roles of pedagogy, content, and technology knowledge for the use of technology in education to understand and explain the adoption of technology in teaching practice.

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sustainability

MDPI

Project Report

Okanagan Waterways Past, Present and Future: Approaching Sustainability through Immersive Museum Exhibition

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Abstract: This paper presents *Waterways Past*, *Present and Future*, a research project and exhibition in Okanagan Syilx territory, aimed at increasing awareness of the relationship between people and water towards catalyzing sustainable water practices. The exhibition's multi-channel audio-visual media was designed to immerse, provoke, destabilize, transform and move visitors to take responsibility for water. Drawing on many ways of knowing and doing in the creative process, the exhibition opens different entry points to the research, thus encouraging an interdisciplinary and cross-cultural audience to engage with it. Waterways' contribution to sustainability discourse lies in its empowerment of collaborative inquiry as a way of knowing, understanding and representing our world. The epistemological dimensions of the exhibit present multiplicities embedded in the social life of water, inviting dialogues, shaping cultural narratives and developing new forms of creativity. Through the sensual process of immersion and activation of lateral thinking, the exhibition facilitates connections across cultures, connections that act as agents for social transformation. Waterways' experiential journey transcends our personal and dominant socio-cultural patterns, reaching beyond normative structures to new creative realms shared ethical space.

Keywords: community design; dynamic systems; interdisciplinarity; collaboration; environmental science communication; immersion; museum exhibition

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1. Introduction

Climate change, as reflected in the long-term shifts in temperatures and weather patterns caused primarily by human activities and the burning of fossil fuels, is the most pressing issue of our time [1]. Immersive multi-sensory museum exhibitions make the complexity of climate change more tangible by embedding the viewer in locally relevant spaces grounded in experiential learning [2–7]. Hybrid design spaces between the traditional museum and computational art practices facilitate associative modalities to engage visitors in challenging concepts [8–10].

As an experiential learning environment, interactive museum exhibits can facilitate a space for the "ontological reflexivity" [11] that enables alternative ways of knowing through multisensory experiences and interactions. They activate lateral thinking and an intuitive grasp of concepts: "*Experiential knowing equally offers all the possibilities to see and understand the world and ourselves within that world in polyphonic, symbolic, artful and imaginative ways*" [12] (p. 79). Immersive multi-sensory environments also provide a space for connection with participants in collaborative activities, renewing a sense of being part of a larger social structure [13]. The experiential aspect of immersive media highlights the transformative capacity of creative spaces of inquiry.

Conceptions of sustainability involve imagining new ways to live and relate to each other and our environment. Sasha Kagan [14] writes about cultures of sustainability that reach across all areas of our being, knowing and doing. The change process entails identifying and developing cultural narratives of sustainability that are energizing and motivating narratives that nurture human energy and promote activities that positively influence human and environmental health. Success stories and visions focusing on reciprocal relationships between people and the environment empower sustainability practices [15]. Given the cultural roots of the climate crisis, its resolution requires new and renewed creative cultural approaches. As catalysts, art and culture can significantly contribute to social transformation for a better quality of life for all living beings [16].

Social change happens incrementally within our place as things transform through practice. Social shifts evolve in how we organize and relate to one another to transform cultural and societal institutions and build communities. Change processes that affect our collective and individual behaviors and worldviews have many influences [17–19]. Some are explicit, and some are subtle. The assumptions and metaphors we use to reconcile our experiences characterize how we see the world.

How can we come together as communities to realize environmental resilience, defined as the capacity of a socio-ecological system to withstand and recover from disturbances while maintaining its function and well-being [20]? How can contemporary media add to themes of sustainability and transformative processes we need to engage in response to the environmental crises we created? We explore these questions through a discussion focused on *Waterways—the Past*, *Present and Future*, a research-creation project and exhibition aimed at communicating water sustainability concepts via immersive experiences of the local Okanagan environment and community (hereafter referred to as *Waterways*, see Figure 1). The Waterways exhibit was created on the territory of the Syilx (Okanagan) Nation, a transboundary people in British Columbia and Washington State that have resided in the Okanagan region for millennia.

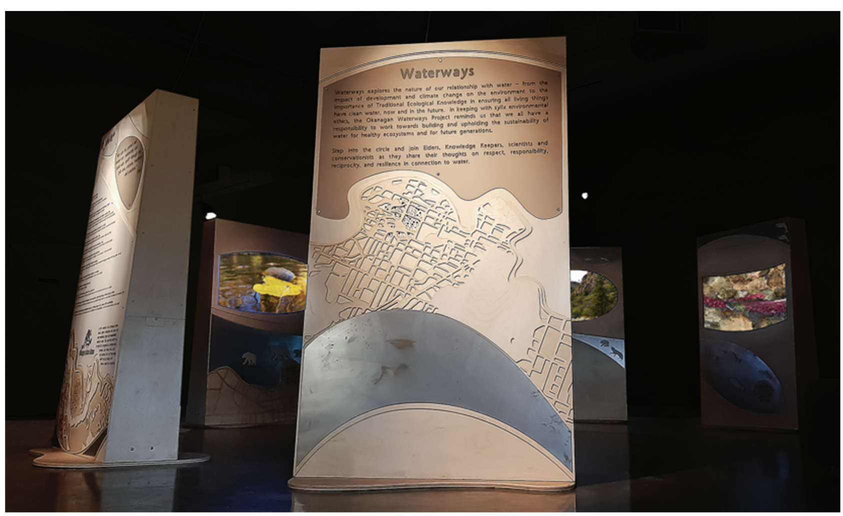

Figure 1. The Waterways Exhibition at Okanagan Heritage Museum, Kelowna, in September 2021. The image shows seven modules in a circular arrangement designed for touring across Okanagan. Source: Photographed by: Sepideh Saffari.

The Waterways exhibit represents a collaboration between a team of Syilx and non-Indigenous scholars and community partners that came together in 2017 to explore the relationship between people and water in Okanagan Valley, one of the most water-stressed regions of Canada. The four-year collaborative research project was aimed at promoting sustainable water practices in the Okanagan through an interactive, immersive museum exhibition that exposes the public to different values, worldviews and ways of thinking about and caring for water, as well as establishing spaces for water sustainability engagements across cultures.

The paper comprises three main sections. The first provides background, including a synthesis of key concepts and contextual and methodological features of the research. The second introduces Waterways and its key design characteristics. And the third brings all the stands of the paper together, providing lessons from the research and exhibit design on cross-cultural collaboration in a real-world context. We end the paper with some brief conclusions.

In the paper, the term Okanagan refers to the name of the Syilx Okanagan people and the geographic location (valley, lake, river) of Syilx traditional lands. In the Canadian context, Aboriginal Peoples include First Nations, Inuit and Métis peoples. First Nation refers to Aboriginal Peoples of Canada who are ethnically neither Métis nor Inuit [21]. We capitalize these terms following guidelines for writing about Indigenous Peoples [21,22].

2. Background

This section provides an overview of key concepts related to exhibition design, including Community Design, Interdisciplinary, Dynamic Composition, Museum and Okanagan context, which all play a crucial role in sustainability discourse, immersive exhibition development and computational design.

2.1. Community Design

Through collaboration and learning with communities about different ways of sustainable living, researchers can connect to new meaningful ideas that contribute to developing new concepts, aesthetics and algorithms uniquely crafted from the community engagement processes. In today's social-ecological context, no single group or person has the lone knowledge, skills and capacity to identify and implement solutions to complex sustainability challenges [23]. The community design process engages all participants as experts based on their lived experiences, with unique contributions, critical knowledge and skills to add to real-world contexts [24]. The collaborative approach can draw from multiple ways of knowing to create sustainable community-controlled, nonexploitative and ecologically grounded solutions and outcomes where social and environmental justice is addressed through the design process and results. The designer is positioned as a facilitator in framing and reframing design solutions [25], using creative processes to sustain, heal, empower and identify effective practices at the community level. The design process seen through the lens of justice provides an environment where the voices of those impacted are prioritized, and the influence on the community is valued over the designer's intention. Design justice as a method [26] honors traditional, Indigenous and local knowledge by integrating wisdom, perspectives and contributions in the design co-creation process. As a process, it positions traditional knowledge systems as invaluable expertise to structure design practices and outcomes, which is critical for sustainability discourse. The focus is placed on both process and product of the collaborative design. Today, design is present in all industries and affects every level of societal structure. Design justice helps us understand the interplay between design, power and social outcomes and reflect on overcoming the reinforcement and reproduction of societal and structural inequalities [26].

In the context of the Waterways project, collaborative design and learning with communities, Syilx Knowledge Keepers, water scholars, scientists and artists who contributed to the exhibit allowed new connections and meaningful ideas to emerge. The meaning-making processes layered within the exhibit are amplified with immersive and sensual media communication strategies. The development of the Waterways exhibit demonstrates how immersive media can express collaborative action and how the community engagement process plays out in the design of the exhibition to enable a reciprocal relationship of exchange, engagement and mutual benefit for the community [27–29].

2.2. Interdisciplinarity

Interdisciplinarity is essential to approaching sustainability, but the term interdisciplinarity still implies a relationship between individuals with different backgrounds. Indeed, the sustainability of individuals makes little sense in isolation. Civilizations and species live and die as groups, forming "cultures of sustainability" [14] essential in formulating sustainable futures. Robinson [30] notes the importance of strengthening challenge-driven interdisciplinarity. The challenge-driven research refers to an inquiry conducted with diverse groups and individuals as co-creators rather than audiences of knowledge and focuses on the practice of co-creation. Establishing external alliances builds understanding through multiple ways of knowing and doing and embraces complexity through connection. Kagan [16] notes that this opens the possibility of collaboration by inviting participants to engage at the intersections of disciplines, which he refers to as transdisciplinary research. Interdisciplinarity offers the potential to combine knowledge from reductionist disciplines and gain a more holistic understanding of complex issues; from a practical standpoint, interdisciplinary studies can help address these complex tasks while also considering the intricate and dynamic nature of the challenge at hand [31]. Struggles in conducting interdisciplinary studies persist through differences in disciplinary language [32,33], assumptions, values and goals [33,34], as well as institutional and methodological barriers [30,35]. Sciences, for example, gravitate to quantitative research compared to humanities, preferring qualitative and interpretive validation approaches [36,37].

In the Waterways exhibition, interdisciplinarity reinforced the creation of reflective space for addressing water challenges and brought forward the community's vision of water sustainability solutions in the Okanagan context. The interdisciplinary engagement was critical as it brought people from different disciplines together to work on a shared challenge. The resulting work also opened new space for interdisciplinary dialogue using multimodal communication strategies. By drawing on many ways of knowing in the creative process, the resulting work opens different entry points, thus encouraging a disciplinarily diverse audience to engage with it. These types of collaborations and dialogical spaces are essential resources for addressing sustainability.

2.3. Dynamic Composition

Sustainability as a field of study and computationally driven immersive media art have a reciprocal relationship of exchange, engagement and mutual benefit. Computation allows video, audio and photography to effectively create relational and emergent compositions that articulate new patterns through novel juxtapositions of media modes. As an extension of mass media communications, digital technologies embody shifting innovations in hardware and software, enabling new expressive platforms for social and cultural interactions and research. Expanding means for data collection and manipulation provide field researchers with new recording approaches, sophisticated databases, diverse processing techniques, and efficient transcription and translation software [38–40]. Concurrently, new representational possibilities afforded by computation can convey cultural meaning as a complex product constructed from multiple sources and contributions to create vivid, sensual narratives [41,42]. Computational affordances of digital media allow creators to design integrative dynamic processes that respond in correlated and co-dependent ways to the environment and each other, expressing equilibrium, which can act as a powerful narrative device [43]. Sustainable practices require attention to relationships in flux, events that need reimagining, and conditions that demand multiple responses and weaving of different perspectives, including shared values, contradictions and competing interests.

As a flexible media journey, Waterways integrates multiple voices and cross-cultural perspectives to critically reflect on our actions and relationships and point to shared values and worldviews necessary for integrated community response. The input capture mode is also a multimodal media source representing the study results. Digital data collection, analysis, and display locate collaborative Waterways research and exhibition development. The Waterways exhibit provides an example of community-engaged interdisciplinary collaboration resulting in a dynamic exhibition that addresses water sustainability in the Okanagan from multiple community perspectives.

2.4. Immersive Exhibition Context

The sustainability of socio-environmental well-being in the age of the Anthropocene is a complex and dynamic environmental, cultural and political challenge. Climate change is restructuring how we live, our relationship to nature and humanity's place on earth in the present and the future. It is a global force with local effects, requiring place-based and community action. The climate change responses are more effective if aligned with sociocultural values that frame the solution development through community engagement processes [44]. Community dialogues at all levels and scales of human activity are critical as climate change affects every aspect of life. Museums, as reliable sources of information in the public sphere, are uniquely positioned to take an essential role in public social-environmental sustainability discourse and community-based climate change visioning.

The use of digital media in museums extends from a long tradition of material immersion and communication, blurring the boundaries between physical and virtual objects and experiences [45,46]. However, as with other sectors that are adapting to emerging media in the time of the Anthropocene, the abundance of new forms of technological platforms and designs raises questions regarding how new forms of museum exhibits can stay relevant for the places and communities they serve [47,48] and how can they promote trust, diversity and socioenvironmental justice through new forms of engagement while supporting personal agency, identity and social interactions in acquiring knowledge and creating spaces for community dialogue [49].

Immersive museum exhibits can combine process-driven computational modelling and visualizations, thus providing a valuable format for expressing sustainability practices through aesthetic experiences, allowing multiple ways of knowing and understanding our environment to intertwine. As applied to mediated audio-visual experiences, immersion can be defined as a psychological concept rather than a property of a technological system [50]. Immersion is a state of deep mental involvement. The individual may experience disassociation from the awareness of day-to-day life due to a shift in their attentional state. Immersion is a subjective experience of being surrounded by multi-sensory stimulation. Immersion can be achieved through various means, including technology, art and storytelling. The goal is to create an engaging, memorable and impactful experience that leaves lasting impressions. Immersive museum exhibits engage audiences and visitors using cognitive and affective strategies to reach the public across cultures and generations and play an active role in co-creating narratives with exhibits that facilitate discussions and enable affective engagement with challenging concepts [51,52].

Examples of museum exhibits focused on sustainability are discussed in detail in Appendix A. These cases aim to empower creative response action in the context of their place. The works discussed include *Arcadia Earth* (2019–2023), *Eye of the Climate* 2 (2020–2023), *Reefs on the Edge* (2012–2017) and *InterANTARCTICA* (2008–2010). These interdisciplinary exhibits relate to the Waterways' experimentation and use of scientific data, photography, video, sound, computational compositions and tangible user interfaces to provide immersive educational space for reflection on climate change challenges. These works share the creative element in designing immersive spaces that foster creative thinking and thoughtful multi-sensory experiences to evoke participants' unique memories and associations in the place-based cultural and environmental context to motivate personal action.

2.5. Okanagan Waterways Context

Water security is one of the most critical issues in the Okanagan Valley of BC, a region that is one of the most water-deprived in Canada. Despite increased water stresses and the compounding effects of climate change, there is a continued reluctance to embrace sustainable water practices, as evidenced by the region's highest per capita water usage in Canada. The Syilx Okanagan Nation, in contrast, has endorsed its siwɬk^{w} (Water) Declaration [53]. This living document clearly articulates the centrality of water and the Syilx People's responsibilities to always relate to water sustainably and respectfully. Syilx Peoples have an intrinsic relationship with siwɬk^{w} (water), equating water with life and considering water a sacred relation, which must be protected and kept healthy to ensure resiliency and relationship to tmix^{w} that translates as the ecology of the land [54] including the land, water, insects, people, animals, plants and medicine [53].

The Okanagan basin is classified as semi-arid [55], with over 80% of the valley's average annual rainfall lost to evaporation. Despite these water conditions, Okanagan domestic per capita water use is more than twice the national average [56]. Given current water usage patterns and projected population growth, the valley will face significant and persistent water shortages by mid-century [56–58]. While longer, drier summers and more frequent droughts have become the "new normal" in the Okanagan, a pervasive "myth of water abundance" persists among many residents, impeding public understanding of the gravity of the situation [59,60] and the required mitigative actions [61]. The general inertia cannot be blamed on the inaccessibility of information. Water sustainability has been the subject of extensive research and awareness raising in the Okanagan, particularly since the early 1970s with the creation of Okanagan Basin Water Board (OBWB). Instead, inaction on climate change is more likely related to the lack of perceived relevance at the local and personal level and cultural and social norms [62,63].

The complexity of these issues and their cultural, physical and political interdependencies mean that multiple actors must pool expertise and resources to identify, communicate and implement solutions at the local level. Working across Traditional and Western knowledge systems, meaningful collaboration with Indigenous Peoples and local communities is critical for climate-resilient development and action [44,64]. The Okanagan Nation Alliance (ONA) and their member bands have been at the forefront of environmental restoration following decades of development-motivated land-use practices, population growth, and their corollary damage to ecosystems. Some of these initiatives have been a focus of the Waterways exhibit.

3. Waterways: Past, Present and Future

Waterways—the Past, *Present and Future* is a four-year research-creation project involving researchers from the University of British Columbia Okanagan (UBCO), Syilx Knowledge Keepers and local partners (Supplementary Materials).

The Waterways research and exhibition aim to foster sustainable water practices by exploring the human–water relationships in the Okanagan Valley. The Waterways exhibition opened in September 2021 at the Okanagan Heritage Museum in Kelowna, BC and is touring across the Okanagan Valley (see Figure 2).

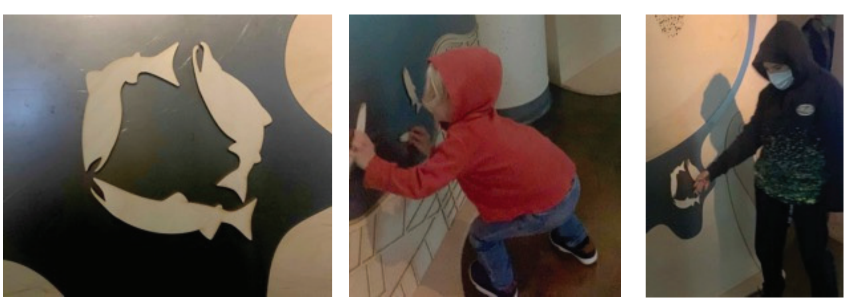

Figure 2. Waterways Exhibition at Okanagan Heritage Museum, showing kids playing with exhibition elements. Source: Photographed by: Aleksandra Dulic.

Waterways research was conducted by a large interdisciplinary group of artists and scientists, both Indigenous and non-Indigenous, with expertise in Indigenous studies, fine arts, media studies, environmental anthropology, environmental science, computer science, social-ecological complexity and architecture. Scholars with extensive experience in collaborative design, immersive technologies, participatory research, complexity science and Indigenous research led the team. Syilx scholars worked with non-Indigenous scholars to guide and oversee critical junctures, including methods and exhibition design. The museum installation reflects the contributions of the interdisciplinary, cross-cultural team, integrating immersive media design to share multilayered narratives representing the exhibition's core concepts of human–water relations. The importance of bridging intercultural and interdisciplinary ways of knowing is reflected in recorded audio and video of interviewees and documentation of the environmental and cultural detail of the Okanagan landscapes, soundscapes and communities.

3.1. Inner Space

The Waterways exhibit's internal walls are designed as a circular space with screens showcasing ongoing narratives from Syilx Knowledge Keepers from Okanagan and Colville Confederated Tribes and Western specialists discussing the significance of water and water stewardship. These screens are layered with audio and video clips of Okanagan water, land and soundscapes.

The space is designed as an immersive multi-channel sound and video media installation. The inner walls of the panels comprise seven modules with five video screens where visitors experience imagery of the Okanagan landscape (Figures 3 and 4).

Figure 3. Okanagan Hills: Five side-by-side frames showing an example of Waterways system-generated video composition. Source: Photographed by: Aleksandra Dulic.

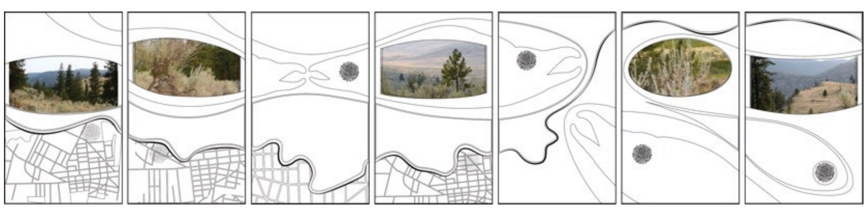

Figure 4. A diagram of the Waterways Inner space module design. Source: Created by: Sepideh Safari and Aleksandra Dulic.

The audio-visual media impress the beauty and sensitivity of various ecosystems throughout the Okanagan region. The exhibition environment provides an immersive cinematic experience that brings diverse voices together around common themes of personal and collective water responsibilities in the Okanagan. The media and exhibition design framework were collected through a four-year process of shadowing Indigenous Knowledge Keepers and experts on the Land at the En'owkin Center, focusing on Syilx values, protocols and land-based knowledge. The recorded material includes the environmental and cultural detail of the Okanagan environments, soundscapes, community events and interviews.

Narratives include descriptions of Syilx Indigenous-led best practices in water stewardship and ecological resilience, including riparian restoration along Shingle Creek and Okanagan River and the restoration of Sockeye Salmon (Taʔánya; *Oncorhynchus Nerka*) populations in Okanagan waterways. These initiatives demonstrate how Traditional Ecological Knowledge (TEK) is applied along with Western science and how Indigenous institutions have worked effectively with partner agencies to lead and co-manage these restoration efforts. TEK can be summarized as Indigenous systems of knowledge and the cultural practices and methodologies related to knowledge production based on land-based systems of beliefs and practices. ONA defines TEK as "*The intergenerational history and oral record of the Syilx Okanagan people, the collective laws, teachings, governance structures and principles that, together, define and inform Syilx Okanagan title, rights and responsibilities to the land and their culture, passed on through direct contact with the environment*" [53]. Conceptually, these success stories and examples of environmental restoration provide seeds of hope and point to the best practices rooted in local ecology and relationships critical to sustainable futures.

The Waterways research team interviewed Syilx Knowledge Keepers, community members and Western-trained experts to communicate these stories. Interviewees discussed the meaning of water, innovations in water ecosystems management and sustainability, new co-management arrangements for caring for our water and ecosystems and lessons from these practices for the future (e.g., Figure 5). Twenty-five interviews and two focus groups with 32 participants were conducted, analyzed and included in the exhibition.

Figure 5. Dr. Jeanette Armstrong's focus group with underwater footage of Sockeye Salmon in Shingle Creek. Five side-by-side frames show an example of Waterways system-generated video composition showing a community reflection on one screen. Source: Photographed by: Aleksandra Dulic and Miles Thorogood.

Interviews: A mixed research team comprising Syilx and non-Syilx scholars conducted and analyzed fourteen interviews in the Okanagan. Seven interviews focused on the return of Sockeye Salmon and seven on restorations and resilience in the Okanagan, including a focus on the ECOmmunity Place. Interviews were semi-structured and open-ended to prompt conversation and video-recorded. The interviewing protocol brought a bi-cultural perspective to the interpretation and meaning-making of interviews and helped to bring cross-cultural understanding and nuance from interview data. A Syilx scholar conducted the remaining eleven interviews with Syilx members of the Colville Confederated Tribes from Washington State in the US.

Focus groups: A Syilx team member conducted two focus groups used in the exhibition. The first focus group comprised ten non-Indigenous participants with scientific backgrounds from Washington State, USA, with a discussion that focused on the Columbia River system. The second focus group comprised three Syilx Knowledge Keepers and scholars and one scientist focusing on Okanagan waterway systems.

The audio-visual modules are arranged in a circle to incorporate the gallery's entire floor area, allowing visitors to travel inside or outside the circle (Figure 6). The circular arrangement aims to generate an additional sense of tangible experience that gives visitors a sense that they are a part of the exhibit conversation. The content is organized through themes that allow diverse community voices to interplay around a common topic. Each voice occupies one screen at a time and is accompanied by footage of Okanagan ecology related to the conceptual framework on display (Figure 5).

Waterways' flexible and custom-designed composition system comprises multi-screen networked displays integrating non-linear sequencing. The system uses the re-combinatory approach to vary viewers' media experiences continuously. The stochastic video and audio sequences are displayed from discrete media segments over a distributed network of modules. Each of the five modules includes a computer, an LCD screen and two-channel audio embedded in a constructed display, with one speaker at the front of the box and another on the rear side to spatialize sound in installation contexts.

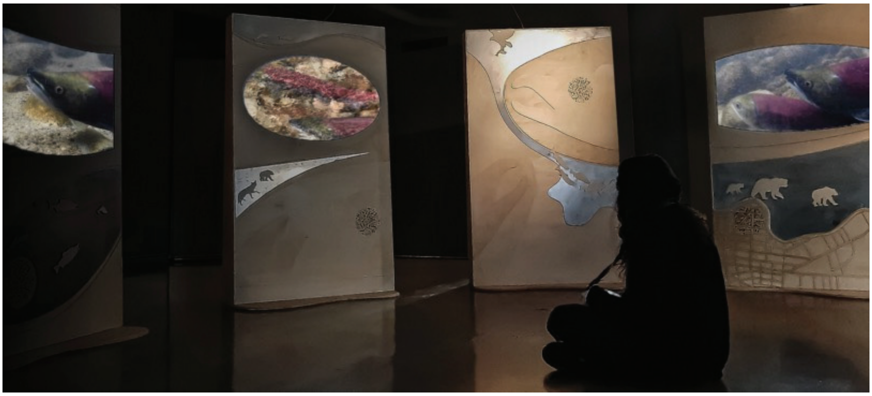

Figure 6. The Waterways Exhibition at Okanagan Heritage Museum shows four modules positioned in a circular arrangement designed for touting purposes. Source: Photographed by Sepideh Saffari.

Media content includes a database of video and audio clips indexed by tags representing a particular concept. The system chooses a topic from the database, plays a sequence of interview clips and selects accompanying environmental footage and audio recordings to disperse across the screens and speakers in the system. The system conductor analyzes the database and, at run-time, moves between concepts based on a specified interval. A local Wi-Fi network provides the infrastructure for communication between the conductor and players. Each video and audio channel are addressed independently, with the system management computer that acts as the conductor, serving file requests to the modules in the audio-video orchestra (Figure 7).

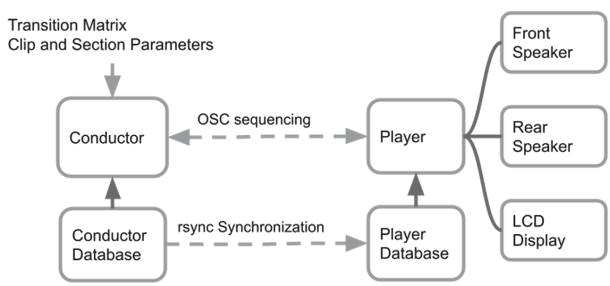

Figure 7. A diagram of the Waterways composition system [65]. Source: Created by Miles Thorogood.

Inner Space Themes

The resulting experience emerges through ever-changing conversations around core exhibition themes. Interview clips are conceptually and spatially linked to environmental images and sound structured according to the following themes:

The value of water integrates Syilx Indigenous and settler perspectives, stressing concepts that equate water with life and an essential relation. Syilx Peoples' responsibilities as caretakers of Okanagan waterways are highlighted in this section.

Traditional Ecological Knowledge (TEK) focuses on what this knowledge–practice–belief system comprises, its contemporary significance for understanding how ecosystems work, and how TEK and Western science can complement one another in dealing with the critical environmental and natural resources issues we face today.

The successful return of Sockeye Salmon to the Okanagan waterways after the canalization and damming of the Okanagan River, north of the Canada–US border and Columbia River system and its tributaries and the near-disappearance of Sockeye Salmon. Syilx leaders spearheaded this 20+ year endeavor.

Adaptive co-management of environment and natural resources, a power-sharing arrangement between governments, local resources and stewards, brings structured learning by doing and adaptation to environmental and natural resource practices (Figure 8).

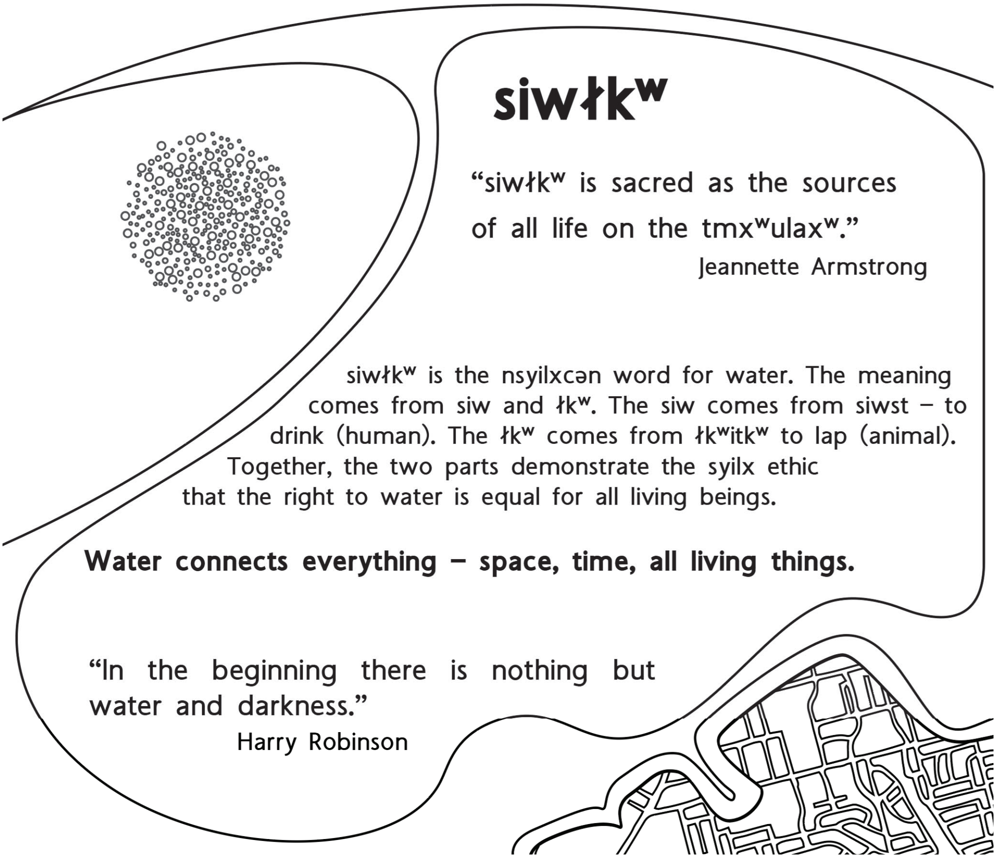

Figure 8. Design diagram of one of the Outer panels showing an interpretive text focused on the Nsyilxcn expression of water—siwɬkʷ word and concept. The meaning of the word embodies the Syilx ethic of the right to water for all living beings. Source: Drafted by Sepideh Saffari.

The Columbia River Basin, of which the Okanagan River is a part, includes the status of the Columbia Basin Water treaty, being re-negotiated between Canada and the US and stories of change and destruction of water and land habitats from Elders who have lived through the changes.

Restoring habitats, such as cottonwoods and riparian systems, to increase the productivity of yellow-breasted chats (xwaʔɫqwiləm, Icteria virens auricollis) and other species at the ECOmmunity Place between the Okanagan River Channel and Shingle Creek on the Penticton Indian Reserve.

Injustice and racism endured and experienced by Syilx Indigenous communities in their efforts to restore their relations with Syilx Lands and Waters, and the resilience of the Syilx Nation in the face of this mistreatment and injustice.

3.2. Outer Exhibit Space

The outer panels of the exhibit highlight Indigenous Syilx teachings and wisdom related to human–water relations and the value of water through five interpretive panels.

Visitors also encounter two touch screens showing a realistic 3D virtual world depicting pre-contact Kelowna.

The Waterways Project reminds us that we all have a responsibility to work towards building and upholding the sustainability of water for healthy ecosystems and future generations, according to Syilx environmental ethics. The five interpretive panels include the text and quotes focusing on key concepts in the exhibition (Figure 8).

One of the outer panels displays the Okanagan Nation siwɬkʷ (Water) Declaration. In 2014, members of the Okanagan National Alliance signed a declaration that asserts their relationship, rights and responsibilities relating to water. They declare siwɬkʷ "*has the right to be recognized as a familial entity, a relation, and a being with a spirit who provides life for all living things.*" ONA [53] (p. 3). The declaration affirms Syilx Peoples' relationship with water and their responsibilities as caretakers of lands and waters to ensure accessible, clean and healthy water for future generations. Syilx sovereignty and the right to self-governance and self-determination are affirmed in Syilx laws and customs. The declaration sets out the resolve and path forward for Syilx leadership in water governance.

In addition to interpretive panels, Waterways exhibit visitors experience two units displaying interactive 3D visualizations of Okanagan landscapes and waterways before colonial development that show dramatic ecological changes to flood plains, wetlands and riparian habitats in the last 100 years. Visualizations depict the entire core of the city of Kelowna between Mission Creek and Mill Creek floodplain (Figure 9). The locales focus on the historical characteristics of Mission Creek, Mill Creek, their tributary creeks, wetlands and the floodplain areas of the Okanagan Lake system. The touch-screen interface affords exploration of the diverse sensitive Okanagan ecosystems, including plant, animal and insect species Indigenous to the region.

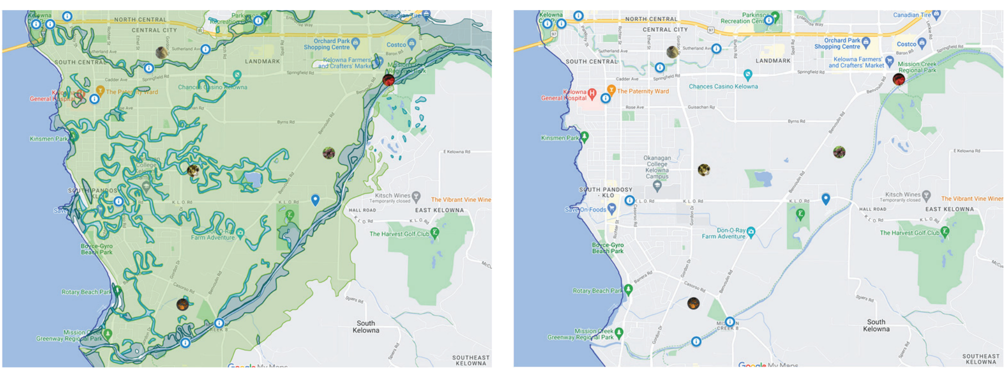

Figure 9. Left: Modified Google map of Kelowna layering the creek systems from 1800 over the City of Kelowna. **Right**: Google map showing Kelowna today https://waterways.ok.ubc.ca/Experience/Waterways-Map.html (accessed on 19 October 2023). Source: Created by Alex Lake.

The interactive virtual environment enables the exploration of two layers: historical and contemporary (Figure 10). It overlays the current urban and agricultural development over ecological history visualizations, providing an essential understanding of what we have lost and how much we have transformed our environment. The information and stories embedded in the visualizations offer a creative platform for dialogue and learning diverse cross-cultural, community-based, poetic, traditional and scientific water knowledge and values.

Figure 10. From the same angle in the visualization, the left image shows the historical layer, while the right image shows the contemporary layer with current Kelowna development. Source: Screenshot by Jordan Pike and CarlaMather.

The Historical Layer is based on diverse records that refer to the Okanagan landscapes before settlers developed the valley, based on scientific, GIS and environmental history data before colonial times. We referenced the list of plants and animals from the En'owkin Center, Okanagan Heritage Museum archives and environmental history literature of the Okanagan basin. Data gathered include plants and animal species provided by Indigenous Syilx Knowledge Keepers, naturalist records [66–72], historical agricultural descriptions [73] and the Okanagan Historical Society's publications of local historical writings since 1925. Historical aerial photographs and archival land tenure maps are combined to re-construct terrestrial ecosystem mapping [65] for 1800 and 1938 with the raw data. We used available 3D animal and plant models and built assets for location-specific characteristics for the Okanagan spices to account for missing items (Figures 11–13).

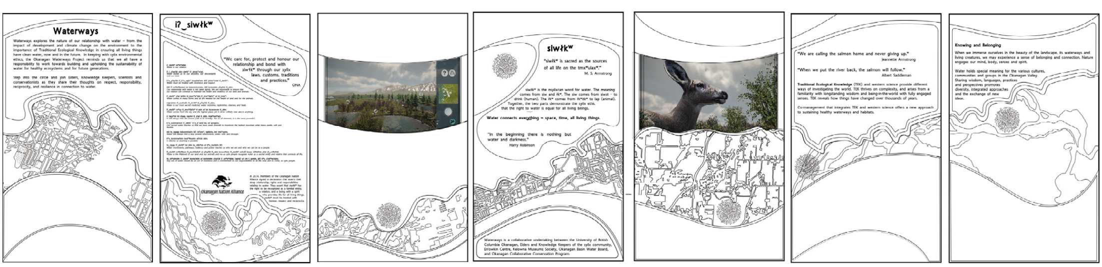

Figure 11. A diagram of the Waterways Outer space module design. Source: Sepideh Saffari.

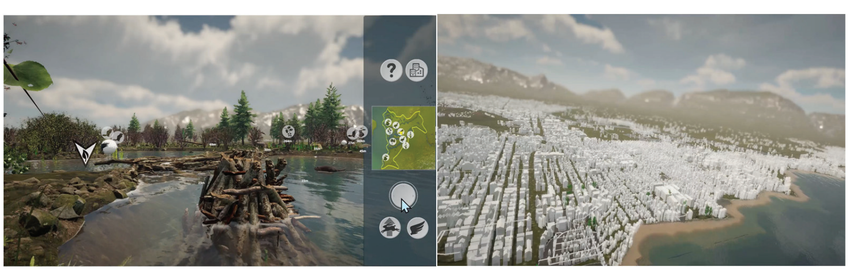

Figure 12. The left image shows pre-contact visualization of a beaver dam. The right Image shows the contemporary layer with the current Kelowna development. Source: Screenshot by Jordan Pike and Carla Mather.

Figure 13. From left to right, top to bottom: 1. Stunx—Beaver swimming; 2. Beaver dam; 3. Sq̓əq̓axʷ—The Western Screech Owl; 4. Sƚ̓úlƚc̓aʔ—Mule Deer; 5. sníkʼƚc̓aʔ—Elk; 6. Sk əm ʼxist—Black Bear; 7. Sʔitwn—Sandhill Crane; 8. Panel showing information for each animal and plant in the world. Source: Screenshot by Jordan Pike and Carla Mather.

The Contemporary Layer is constructed based on publicly accessible geospatial data from the BC Data Warehouse and Google map records. This provides information detailing terrestrial ecosystem mapping, vegetation resource inventory, sensitive ecosystems inventory, lakes and streams and community water-shed boundaries (Figures 10 and 12).

The visualization enables an imaginative space for ***Okanagan futures***. The present overlays the past, pointing to possible restoration opportunities in the future. Kelowna's urban neighborhoods can be viewed with the representations of local sensitive riparian ecosystems of the past. The content shows the past and what we have lost with rapid development. It represents knowledge regarding ecological changes within the floodplain area to express possibilities for better care for creeks, wetlands and riparian habitats today and in the future. The project has the potential to mobilize and inspire the public for grassroots re-wilding of the city.

Interactivity allows learning and engagement by providing accessible and experiential representations of the complex environment across space and time. Historical visualizations offer a virtual space for reflection, discovery and exploration, enabling experiential learning through immersion in the past. Participants can explore historical wetland habitats and microenvironments.

Each local plant and animal encountered provides an opportunity to learn about the species and their Nsyilxcn name. Nsyilxcn is the language of the Syilx Okanagan People and belongs to the Salish language family [74].

Information for each species conveys their interdependence across the Okanagan's sensitive ecosystems and their role in providing water security and resilience for an interconnected living system. Audiences can listen to the Knowledge Keeper's reflections on the past and compare the natural habitats against the current agricultural and urban development. Two Knowledge Keeper's reflections were used with permissions from the interviews recorded and conducted by Dr. Sam's (2008) [75], and one interview was recorded by our team in 2021.

Understanding what we have lost and how much we have transformed our environment is essential. We live in a world of continually shifting baselines where our collective memory forgets what things were like more than the length of a human lifetime ago. The immersive environment allows us to step back and think about what it might have looked like in the area for people who lived here less than 100 years ago. As you walk through the floodplain, what might you encounter? So many species of plants and animals cannot be found in Kelowna anymore. Grizzlies, caribou and elks were all moving through what is now an urban and agricultural environment.

4. Discussion: Bringing the Threads Together

Galanter [76,77] argues that computationally driven media "*is uniquely positioned to negotiate between science and the humanities*". He defines it in terms of complexity theory, a branch of study that deals with "*how relationships between parts give rise to the collective behaviours of a system, and how the system interacts and forms relationships with its environment*". He argues that, while science traditionally holds a modernist viewpoint and the humanities have tended towards postmodernism and an organizing worldview, complexity as a worldview is the synthesis of modern and postmodern modes of thinking, indicating the critical need to develop new language, metaphors and worldviews that can support us in addressing the environmental challenges we created. Complexity opens up a third space for science and humanities to engage with each other through the world they represent and make it accessible for community reflection.

Immersive media's potential for interactivity, and multivocality, in spatialized representations of sensitive cultural narratives, demands community-based collaborative development. The constant re-exploration of the media materials within the work resonates with a culture of sustainability, where social practices can directly contribute to community regeneration. Through the experience of flexible media art, perhaps we can learn what it means to re-imagine our actions and relationships continuously and critically with our community context. Understanding the sustainability challenge through this multiplicity of viewpoints enables cross-cultural dialogue to reveal a shared ethical space from which we can act as a community. From individual experiences to shared community values and worldviews, communities can shape their places to create significant societal change.

Cultures of sustainability hold many simultaneous, complementary and contradictory worldviews, and each of these lenses is valuable and incomplete. These multiple cross-cultural viewpoints and disciplinary perspectives give rise to further diversity of values, beliefs and needs. It informs how we understand our world in the context of the whole, to diverse communities of practice and how we interact with each other and our environment. Through creativity and sensual experiences, immersive media art provides a ground for meeting and grasping those diverse worldviews simultaneously, informing our place in the world and enabling us to position our actions as cognizant and compassionate for the diversity surrounding us. The sustainability we address through the Waterways exhibit focuses on a mindset, worldviews and relationality. We see sustainability as a holistic idea constantly shifting to accommodate new understandings of the mutual impacts between our surroundings and ourselves. In the remainder of this section, we explore the notion of Community Design, Interdisciplinarity and Dynamic Composition in the context of the Waterways exhibit. As we do so, we position them through the sustainability discourse.

4.1. Community Design

Community-engaged collaborative design involves engaging participants as partners in mutual learning and knowledge creation [23]. However, cross-cultural collaboration and knowledge sharing between Indigenous and settler communities require careful consideration. Canada's legacy of colonialism has left an indelible mark on Indigenous and Aboriginal peoples, which continues to affect their psychological, social, cultural, and economic well-being [78,79]. Moreover, in British Columbia, where most of the provincial territory is unceded [80], the rights of Indigenous people and their singular role in society are foundational for any collaboration. Furthermore, the environmental issues directly or indirectly affect Indigenous lands pointing to the significance of effective cross-cultural collaboration approaches.

Divergent worldviews and relationality to the land profoundly influence cross-cultural collaboration in the Canadian context. Characteristics of worldviews shared across Indigenous groups include the world being seen as a whole, as an interdependent and interconnected living system in which humans are an integral part of nature, grounded in a philosophy of egalitarianism towards all life forms and non-human entities [54,81–83]. Features of the Western worldview, in contrast, are based on anthropocentrism. This philosophical viewpoint places humans as the world's most central and significant entities and regards humans as separate from and superior to nature [84]. At the same time, other living and non-living things (e.g., animals, plants, minerals) are resources that may justifiably be exploited for the benefit of humankind, wealth generation and comfort. This dominant, hierarchical and detached relationship between humans and nature contrasts sharply with the Indigenous worldviews based on equal partnership with all living beings inhabiting the land and waters.

Waterways media and interviews subsequently used for the museum installation reflected the Syilx People's cultural protocols, values and beliefs to include the needs of the whole living system of tmix^{w}. Armstrong points out that in the Nsyilxcin language tmix^{w} refers "*to the ecology of the land, including all life forms of a place, consisting of many relationships*" [54] (p. 96)—the land, water, insects, animals, plants, people and medicine where humans are an equal part of tmix^{w}. "*Sustaining, strengthening, and protecting each tmix^{w} in an equality of existence through the cycles of days, seasons, and years requires the knowledge that being human is a tmix^{w} responsibility*" [54] (p. 96). Armstrong discusses the parallel between aspects of a deep ecology paradigm and the Syilx perspective, particularly concepts of interrelatedness with the environment as an epistemology of ecological egalitarianism towards all life forms, which represents a philosophical foundation for engagement with the Syilx community. The Nsyilxcin word Syilx similarly refers to "*responsibilities that individuals have to take care of this land and its people through songs, prayers, ceremonies, language, and traditional practices*" [85] (p. 23). Syilx is derived from the root word Yil, which signifies taking many-stranded fibers and weaving them together to form one unit to convey the idea of continuously binding with others, extending beyond humans to encompass all forms of life that make up the land. This emphasizes the interconnectedness of all beings and the importance of collective unity. The x at the end of the word signifies a command directed at the individual level. Each individual is instructed to actively participate in and contribute to binding and unifying with each other and the land [86]. The non-negotiable obligation of Syilx stewardship of the tmix^{w} is to act as caretakers of their lands. Embedded within this principle is the concept of respect and reciprocity. "Caretaking" and "stewardship" share protocols in which humans approach the world with the attitude of respect to interconnected entities and collectives, which have reciprocal relationships with one another [87].

The captik^{w}ɬ(i.e., stories) provide an ethical roadmap and system of intergenerational knowledge transmission [54,81]. According to Armstrong, "*captik^{w}ɬconveys the Syilx people's inextricable connection to the natural world and is fundamental to the dissemination of the Syilx environmental ethic*" [76] (p. 106). Furthermore, the convention of captik^{w}ɬis a method for humans to continuously learn, understand and be guided to implement the life principles required to sustain a regenerative environmental ethos.

Indigenous values equating siwɬk^{w} (water) with life and as an essential sacred relation of all things in tmix^{w} were reflected in the exhibition. The exhibition materials highlight the Syilx cultural and existential significance of restoring Sockeye Salmon and the cultural imperative of restoring Okanagan habitats, riparian systems and biodiversity. Furthermore, the artwork generated through Waterways focused on creating an imaginative space of engagement and reflection on multiple realities and worldviews embedded in the "place" of the Okanagan.

The design of the Waterways exhibits reinforced cross-cultural and interdisciplinary understandings, collaboration, knowledge sharing and multidirectional communication discourse on water responsibility (Figures 14 and 15). Research participants brought their views and perspectives into the collaborative knowledge-generation process as a prerequisite for cross-cultural understanding. This collaborative knowledge generation process nurtured shared understanding and supported the team's ability to work together effectively. Iterative shared working processes were central, from conceptualization and design to museum production.

Figure 14. Salmon Release Ceremony in Penticton in May 2018, displayed in the exhibition. Columbia River Salmon Ceremony engages youth to encourage the next generation to continue the work to bring the salmon home. Around 10,000 young salmon are released into the Penticton River Channel annually as part of the Okanagan Nation's efforts to rejuvenate the local salmon population. Source: Photographed by Aleksadra Dulic.

Figure 15. Chief Chad Eneas with his nephew, May 2018. Used with permission. Source: Photographed by Aleksadra Dulic.

The collaboration and learning with communities, Syilx Knowledge Keepers, water scholars and scientists who contributed to the exhibit content and design allowed new connections and meaningful ideas to emerge. The meaning-making processes layered within the exhibit are amplified with the uniquely designed software applications responsible for media control and display. Thus, the collaborative design process contributed to cross-cultural sharing enabled by algorithms and aesthetics framework uniquely crafted from the community engagement processes. The development of the Waterways media exhibit demonstrates how computationally driven media art and the fields of sustainability have a reciprocal relationship of exchange, engagement and mutual benefit [27–29]. Concurrently, communities and those individuals have access to the techniques and ways of understanding the world that bring value through developing new modes of public engagement. As an experiential journey, the Waterways exhibit transcends dominant norms by sharing diverse perspectives and successful partnerships to elucidate shared ethical space.

4.2. Interdisciplinarity

Immersive media afford numerous ways of representing sensitive knowledge, requiring unique expertise. Collaborations among artists, Indigenous scholars, scientists, anthropologists and computational experts proliferate how we can communicate knowledge about people, habitats and places, articulating ideas through landscapes, soundscapes and interactions that create sensual experiences. An expanded sensorium of knowledge articulating cultural meaning is commonly experienced in galleries and museums [40]. These trends reflect and represent many ways cultural anthropology, technology design and fine arts are embedded in the contemporary media ecology.

The transformation toward sustainable, reciprocal and responsible relationships with the natural world is a complex challenge with many interconnecting and often competing facets. It is critical to have interdisciplinary perspectives when addressing sustainability and open spaces for dialogue and synergies across diverse viewpoints to facilitate new ways of approaching the challenge, finding common ground and considering a full range of goals. As a complex media system, the Waterways exhibit used an interdisciplinary approach to explore liminal spaces between and around disciplinary fields. The Waterways research team comprising a large multi-disciplinary group of artists and scientists from UBCO, both Syilx and non-Indigenous, as well as community partners, reflected the aim of collaboration and transdisciplinary research. The partners included the En'owkin Center, the ONA, the Kelowna Museums Society, the Okanagan Collaborative Conservation Program and the Okanagan Basin Water Board. At UBCO, Waterways worked out of the Center for Culture and Technology to bring together researchers on complex environmental systems and adaptation, de-colonization and Indigeneity, biodiversity and resilience (Figure 16). An iterative and collaborative creative process was applied throughout the research and design to capture the richness of interdisciplinary practice. New knowledge and artwork developed for the museum exhibition, for example, evolved through collaboration between cross-functional team members and were shaped by research and community partners. Waterways served as a design container for interdisciplinary views and sources of scientific, anthropological, artistic and community knowledge, from which meaning and multiple ways of knowing were derived.

Figure 16. The outer panels of the exhibit highlight Indigenous Syilx teachings and wisdom related to human–water relations and the value of water through five interpretive panels. Visitors also encounter two touch screens showing a realistic 3D virtual world depicting pre-contact Kelowna. UBCO team testing the installation in the museum. Source: Photographed by Joanne Gervais.

The Waterways Project reminds us that we all have a responsibility to work towards building and upholding the sustainability of water for healthy ecosystems and future generations, according to Syilx environmental ethics. The five interpretive panels include the text and quotes focusing on key concepts in the exhibition.

One of the outer panels displays the Okanagan Nation siwłk^{w} (Water) Declaration. In 2014, members of the Okanagan National Alliance signed a declaration that asserts their relationship, rights and responsibilities relating to water. They declare siwłkʷ "*has the right to be recognized as a familial entity, a relation, and a being with a spirit who provides life for all living things.*" ONA [53] (p. 3). The declaration affirms Syilx Peoples' relationship with water and their responsibilities as caretakers of lands and waters to ensure accessible, clean and healthy water for future generations. Syilx sovereignty and the right to self-governance and self-determination are affirmed in Syilx laws and customs. The declaration sets out the resolve and path forward for Syilx leadership in water governance. Moule with 3D pre-contact visualization at the Okanagan Heritage Museum 2021.

For example, the Waterways 3D pre-contact visualizations' design explicitly implements scientific and humanist methods, bridging these interdisciplinary streams with the design processes to co-create interactive 3D environments for communicating culturally grounded perspectives. The unique aspect of our research-creation methodology is bringing different streams of science and design with Indigenous knowledge and philosophy into 3D visualizations. The visualization demonstrates how scientific, academic and practice-based communication can delve deeply into place-based concepts and water sustainability challenges and solutions through collaborative development. As a gathering point for people with diverse backgrounds, the processes behind the creation of elaborate immersive media artwork can provide valuable insights regarding models of working across and between disciplines. Waterways was created in this mode and required that the work consists of an ongoing dialogue between the parties involved in its creation and community validation of the work.

4.3. Dynamic Composition

Kagan writes: "*Cultures of sustainability may inspire hope, but their strength is also their vulnerability. As soon as they crystallize into fixed states, closing their boundaries and fixing their borders, they risk losing their elasticity and porosity down the path of autopoiesis. Cultures of sustainability are a matter of dynamic self-critical exploration. They require a continuous re-actualization of reflexive competencies. For this reason, they demand an artful practice of life*" [14] (p. 10).

Process-driven immersive media emerges through the constant state of becoming. Often interactive, computationally driven artwork can provide a conceptual framework to engage with the active socio-environmental inputs that provide an endless source for varied representations. When interactivity is introduced, the work moves from a single creator and viewer to a responsive system, enabling a multifaceted conversation within a given environment. Computational composition and visualizations in the context of studying and representing cultures of sustainability enable researchers to design immersive experiences that evolve over time and in response to the audiences engaged in the results of the inquiry.

If we position computationally driven, dynamic exhibits as a distinct media type, what forms of messages are embedded in its structure? What themes and ideas are built into dynamic compositions because of their very nature? How does it produce spaces for reflection, re-imagination and grasping the complexity of our place and the world? Can it reveal new relationships between seemingly disparate entities? Does it allow participants to experience new avenues for understanding socio-environmental relationships? How can dynamics in form and content contribute to the process of making meaning?

As a site for disseminating research results, the Waterways exhibit provides a cross-cultural cultural encounter that integrates affect, cognition and meaning using human–computer interaction and media display methods to represent the sensual complexity of cultural knowledge and experience, enabling a complete immersion of audiences in the knowledge and practice that emerges from Okanagan Waterways. The Waterways content, software, hardware and spatial infrastructure were created from the community participation process to enable communication and dissemination of sensory and cultural research that can profoundly impact cross-generational and cross-cultural audiences and the public, taking full advantage of computation's performative and interactive potentials.

Various relationships embedded in the diverse water knowledge, including interviews and audio-visual documentation of the environmental and cultural significance, scientific and historical modelling and visualizations, provide a creative platform for dialogue and learning (Figure 17). The improvisational re-combinatory poetics nurtures new insights and connections to emerge across diverse cross-cultural, community-based, poetic, traditional and scientific water knowledge and values, placing the viewer in the centre of these conversations.

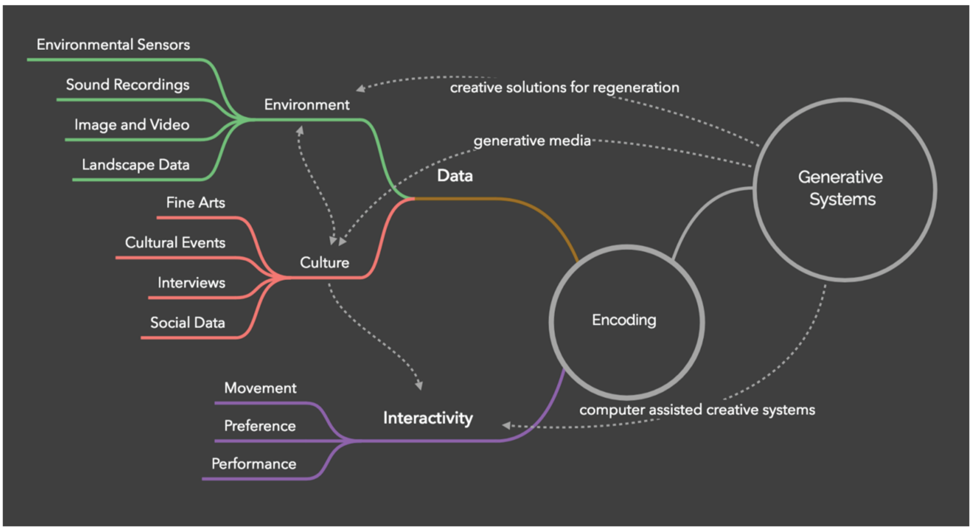

Figure 17. A diagram that demonstrates the relationships between the environment, culture and interactivity mediated through encoded processes by generative systems and reflected in the Waterways project. Source Diagram Created by Miles Thorogood and Aleksandra Dulic.

The computational media enable dynamic, flexible and responsive expressions and composition. This feature provides a fruitful ground for engaging with complex problems. The exhibition is formed through an equilibrium across multiple elements within the system that act together in a co-dependent yet flexible way. This characteristic of computational art is a crucial narrative device to enable an imaginative space of engagement and reflection on the realities embedded in our place: geopolitical issues, histories, futures, resource availability, conflicts, demography, biodiversity and beauty. The renderings of multiple relationships across its components within the art system provide a unique conversational space for a creative engagement with place-based sustainability thinking and practices. The dynamic composition of the Waterways exhibit enabled the poetic search for common ground and cross-cultural engagement to foster sustainable water practices in one of the most water-stressed regions of Canada. The diverse voices in the exhibition exposed the public to different values, worldviews and ways of thinking about and caring for the water.

The contribution of Waterways' research-creation project to sustainability discourse lies in its powers as a means of collaborative inquiry, as a way of knowing, understanding and representing our world. Immersive media exhibits can provide awareness beyond the conceptual framework, building on the capacity to sense the world, which exceeds the ability to categorize the world. The epistemological dimensions of immersive media art can present realities as constructed rather than fixed to invite new cultural dialogues, shape new cultural narratives and develop new forms of creativity. In that regard, immersive media inherit a language of fine arts to create an embodied experience that enables the reception of ideas in a fluid cycle across the sensual and conceptual, facilitating a space for the ontological reflexivity [11]. We approach the Waterways immersive exhibition as a source of ontological reflexivity and an agent of transformation and social change, where foundational knowledge of how communities connect across cultures with water and all living beings is brought into play through a multi-sensory experience that activates lateral thinking and an intuitive grasp of concepts.

The Waterways exhibit creates an experiential journey that transcends our personal and socio-cultural customs to reach beyond our normative structures to new creative territories through the sensual process of immersion. This transcendence through a process of perception means co-evolving with social and personal structures due to improvisational experiences enabled by the artistic system. This empowers the creative engagement of participants to reach perceptual transcendence through immersion in concepts of water reasonability.

5. Conclusions

Waterways exhibit aimed to create a space for exploring water sustainability in the Okanagan, using community engagement processes to develop new tools for sustainability communication, dynamic composition, scientific and historical modelling and visualizations. We bring these interdisciplinary streams with the collaborative design processes to create an ethical space of cross-cultural engagement within an immersive environment. The project demonstrates how scientific, academic and practice-based approaches can work together to delve deeply into place-based concepts of water sustainability.

The discussion of the dynamics in complex systems reflects our dialogues over the four years at the Center for Culture and Technology at the UBCO. As a team, we came together in our interest in water responsibility to develop a new understanding of intertwining nature, art, science and technology. This work aims to bring opportunities for imagining and identifying shared ethical ground for sustainable living solutions. The Waterways project is an example of collaborative design that cultivates cross-cultural knowledge sharing and dialogue regarding sustainable human–water relationships. The project provides a platform for interdisciplinary research, visioning and visualizing local sensitive ecosystems across Indigenous and Western perspectives. The project synthesizes water knowledge and research to catalyze greater ecological awareness and promote more sustainable water use practices among residents. The work explores the multiple meanings of water for the many communities and interest groups in the valley, weaving stories with scientific modelling and visualizations into an immersive experience.

Supplementary Materials: The following supporting information can be downloaded at: https://waterways.ok.ubc.ca/.

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Appendix A

The museum exhibit examples discussed in this section share the aim to empower creative responses to our current climate change challenges and motivate action in the context of their place. Immersive spaces designed to foster creative thinking and thoughtful multi-sensory experience can evoke participants' unique memories and associations in the cultural and environmental context, motivating personal action.

Arcadia Earth (2019–2023 https://www.arcadia-earth.com/ (accessed on 19 October 2023) is a large-scale immersive, interactive exhibition designed to educate visitors about climate change and inspire them to take action, currently on display in New York, USA [88]. The exhibition features 18 installation rooms, each with a unique message and purpose. Combining augmented and virtual reality technology and scenic design, the exhibition takes visitors on a multisensory journey showcasing underwater worlds, mystical forests, and underground caves. A room constructed from 44,000 discarded plastic bags symbolically represents the amount used in New York State every minute. Human consumption is highlighted by using recycled materials to construct installation spaces—plastic bottles, waste electronics and upcycled fabrics. The immersive experience is structured to motivate visitors to make small, everyday lifestyle changes that can have significant collective impacts. An actionable solution accompanies each message in the exhibition focusing on what we can do today to protect the future of our planet. The immersive exhibit intertwines physical and virtual spaces to address the climate change crisis through human needs rather than future threats, focusing on individual and collective action in an inspiring and engaging way.

Another example of an immersive exhibition space produced by the marine center in France, Nausicaá, is designed to educate visitors about the devastating effects of global warming on the ocean and marine life (2020–2023 https://www.modulo-pi.com/showcase/immersive-room-nausicaa/ (accessed on 19 October 2023). This digital exhibit entitled *Eye of the Climate*, which opened in 2020, depicts striking consequences of coastal erosion, marine ecosystems in changing climate, and oceans' essential role in climate regulation; 360-degree projection surrounds visitors with realistic 3D animations of marine life and underwater environments to create a lifelike experience that transports visitors to different ocean parts. This approach conveys complex ocean climate information to trigger visceral reflexes with lasting emotional effects [89]. The exhibition is designed to raise awareness of the effects of human activities on oceans and showcase numerous solutions and best practices that can curb global warming.

Installations by Bérigny et al. [90] *Reefs on the Edge*, 2012–2017 and *InterANTARCTICA* [91], are interdisciplinary artworks that experiment with scientific data, photography, video, sound and tangible user interfaces to provide immersive educational space for reflection on climate change challenges located in Sidney, Australia. These works are examples of the interactive exhibit in the education surrounding climate change. Both installations use tangible user interfaces to shape interaction that invites viewers to engage with climate change science and its effects through embodied, visceral and aesthetic experience. These strategies allow the message of the effects of rising sea surface temperatures on young corals and melting ice in Antarctica to be translated seamlessly across multiple media platforms, creating a perceptible experience that integrates the entire body. In both works, de Bérigny works with a team of interdisciplinary professionals to bring science and art into an integrated interactive experience that engages an audience on embodied, emotional and intellectual levels. These examples highlight the importance of an interdisciplinary team approach in addressing complex problems facing humanity today.

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sustainability

Review

Metaverse as a Learning Environment: Some Considerations

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Abstract: The metaverse is unavoidable in an increasingly digitalized society and will potentially have a profound influence on what is understood as teaching and learning in its formal and informal dimensions, both in initial and continuing education. This research, carried out through document analysis, aims to reflect on several challenges and opportunities that the metaverse poses to education as a source of opportunities for a more relevant and effective teaching process, which necessarily involves the development of both the implementation and monitoring of research studies in the follow-up of education in the metaverse environment.

Keywords: curriculum; ethics; future of education; learning process; metaverse; teaching; virtual classroom; virtual reality

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1. Introduction

According to several authors, we are increasingly living in a super-smart society, characterized by the close connection between artificial intelligence, the internet of things, big data, and man [1–5]. This factor increases the influence of this technology and the way it is mobilized in the (re)definition of one's individual and collective identity [6–8] and the consequent interest in the study of cultures and online communities [1–7].

It was in this context that the COVID-19 pandemic, and the consequent security measures related to physical distance, boosted the increasing implementation of the digital dimension [3,9–11] in many of the sectors of life, of which we highlight for the purposes of this paper. These include education through elements such as online classes, virtual conferences, and lectures, among others [12].

A subsequent phase is the growing interest and presence of the metaverse, which, in a way, deepens the digital dimension in social and economic life and, potentially, in education itself [13–15] in the (possible) development of the United Nation's Sustainable Development Goal 4—quality education. However, the metaverse as a learning environment is a topic that is (still) very little studied [16].

Suh and Ahn [14] point out four reasons for this emergence of the metaverse. Firstly, this trend stems from the technological evolution we have been witnessing. Secondly, as a result of COVID-19 and the inevitability of using virtual communication, of which education is a paradigmatic example. Thirdly, the so-called Generation Z (the digital natives, known colloquially as zoomers) have profoundly changed the consumption patterns of cultural goods. Finally, the massive dissemination of mobile devices (PCs, mobile phones and tablets, among others) and access to the Internet from anywhere and at any time has allowed everyone to access the metaverse.

However, what is the metaverse all about? First, it is pertinent to emphasize that it cannot be confused with any exclusive software program or specific platform exclusive to any company or even of a state/public entity, state, or governmental nature [17–19]. It is not easy to present a single definition [20], but the one that follows seems enlightening to us:

The metaverse is a post-reality universe; it is a perpetual multi-user environment that combines physical reality and digital virtuality. It is based on the convergence of technologies that enable multisensory interactions with virtual environments, digital objects, and people, such as virtual reality (VR) and augmented reality (AR). As a result, the metaverse is a web of social and networked immersive environments on persistent multi-user platforms. It allows for real-time embodied user communication and dynamic interactions with digital artifacts [21] (p. 278).

The metaverse is intrinsically linked to Web 3.0 [18,22] and blurs/fuses the physical and virtual dimensions [23,24] in what Allam et al. [25] call *phygital*. In addition, the metaverse is shaped as a continuity that merges the physical and the virtual worlds, largely through the existence of "avatars" as digital identities [16], a "digital representation of oneself in the digital world" [25] (p. 777), which raises profound and emerging challenges [26].

Given its extreme complexity and novelty, the enormous potential of the metaverse is not yet fully realized [19,22,27,28]. Dionisio et al. [26] point out four characteristics deemed fundamental elements for a fully realized metaverse (Figure 1).

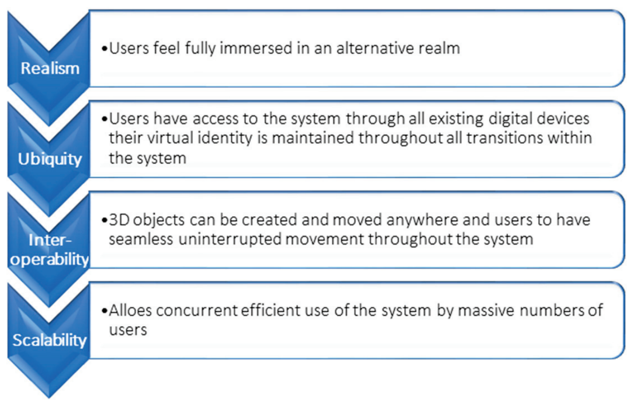

Figure 1. Fundamental elements for a fully realized metaverse. Source: Adapted from Dionisio et al. [26] (pp. 28–29).

This study thus seeks to contribute to a reflection on challenges that metaverse education poses as a source of opportunities for more relevant and effective teaching; it is structured according to the following points: The Metaverse and Digital Society, The Metaverse and Education, Changes in Teaching, and Challenges. The paper ends with the presentation of the conclusions that this study allowed reaching.

2. Materials and Methods

The methodological approach used in this research study is qualitative and the research technique used in the analysis of the data collected was content analysis, as it allows for the compression of a high amount of words and text into fewer content categories based on explicit rules of coding [27–29]. Content analysis is, thus, a powerful technique that allows for filtering large volumes of data more easily and systematically [28,30].

The authors carried out a thorough literature search. The search terms used were metaverse, education, teaching and learning process, virtual classroom, virtual reality, and ethics, which were mentioned either in the title or in the abstract. The search was performed between 2 and 10 September 2022 and the databases searched were B-ON [31] and SCILIT [32]. The B-ON database incorporates the Web of Knowledge, SciELO, and DOAJ databases, among others, whereas the SCILIT database covers all documentation to which a DOI (Digital Object Identifier) has been assigned. This literature search resulted in 51 publications, described in Table 1.

Table 1. Document sources analyzed and their characterization.

Type of Document		Geographical Scope		Year of Publication			
Theoretical/Conceptual	Empirical	International	National	2022	2021	2020	Prior to 2020
45	6	45	6	34	5	3	9
Total: 51 publications							

Source: Authors' production.

The research studies authored by scholars from all the continents are represented in the literature review, albeit with very different weights in terms of their number. The majority of the authors of the research studies analyzed (93) are affiliated with European educational institutions (Cyprus—2; France—7; Germany—2; Greece—1; Ireland—36; Italy—11 Netherlands—1; Norway—5; Portugal—4; Spain—2; Switzerland—1; Turkey—8; and UK—13). The Asian continent follows, with 65 authors (China—17; Hong Kong—3; India—10; Japan—1; Korea—13; Malaysia—2; Qatar—2; Saudi Arabia—1; Singapore—8; Taiwan—3; Iraq—1; Jordan—2; Pakistan—1; and Palestine—1). In third place are the North American authors (28) (Canada—6; USA—19; and Panama—3). The fourth continent is South America, with 6 authors (Brazil—4; Chile—1; and Peru—1). The two least represented continents are Oceania, with four authors from Australia, and Africa, with one author from Morocco, one from South Africa, and one from Tunisia.

3. The Metaverse and Digital Society

The metaverse, as a fully immersive digital environment, is accessed through an avatar with a digital time-space, which is not necessarily the same as the physical world [26,33,34] (for further development, see Mistretta [10]; Abbate et al. [13]; Suh and Ahn [14]; Cui et al. [15]; Zhang et al. [16]; Knox [17]; Damar [19]; Lim et al. [23]; Tlili et al. [24]; Allan et al. [25]; Song [33]; Jiaxin and Gongjing [35]; Khala [36]; and Yue [37]).

Momtaz [38] defines the metaverse as a "[...] shared vision among technology entrepreneurs of a three-dimensional virtual world, an embodied internet with humans and the physical world in it" (p. 228). The defining traits of the metaverse are detailed in Table 2.

Table 2. Defining traits of the metaverse.

Categories	Defining traits
Infrastructure	The metaverse is a persistent virtual system with real-time information processing capabilities that can cause the current state of knowledge to be available to all users at the same time at all times.
Architecture	The metaverse is a decentralized platform that features a high degree of interoperability to enable the mobility of digital identities, experiences, and possessions across the metaverse from one place, event, or activity to another.
Human couth	The metaverse overcomes the limitations of Web 2.0-based virtual realities by enhancing users' self-perception and presence, increasing human interactivity, and improving realistic expressions of human qualities, such as emotions.

Source: Adapted from Momtaz [38] (p. 228).

In turn, Jaber [39] schematizes, in a very comprehensive way, the metaverse architecture with the integration of digital worlds and the human and physical worlds (Figure 2).

Jaber [39] sustains that this complex system is composed of a set of components that include (1) humans (which are at the core of the metaverse); (2) the physical infrastructures (the real/physical world); (3) the interconnected virtual worlds (named the sub-metaverse); (4) the metaverse engine (whose functioning is fed through the use of blockchain, artificial intelligence, interactivity, and digital twin technologies; (5) the in-world information flow (the technologies permanently update the virtual world through the inputs from the real world); and (6) the flow of information across physical and virtual worlds).

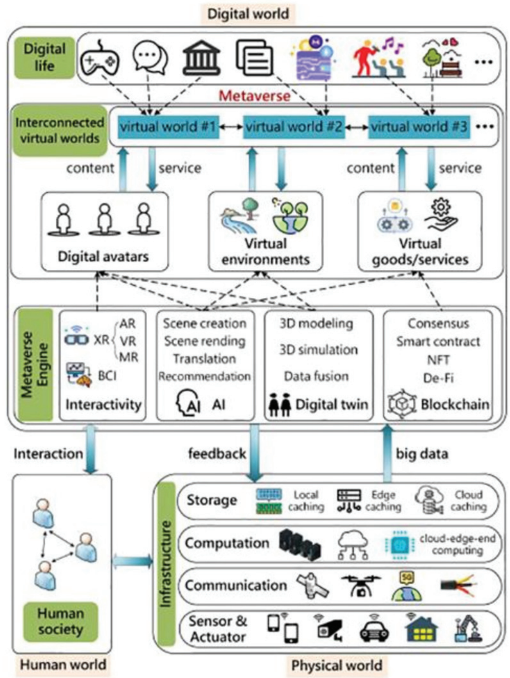

Figure 2. Metaverse architecture with the integration of digital worlds and the human and physical worlds. Source: Jaber [39] (p. 7).

The metaverse will shape the future and even human identity, providing more intuitive ways of human-technology interaction [24]. The metaverse will articulate the representation of individuals in the physical world with their digital representation in the virtual world and the respective forms of communication and interactions [15,17,33,40–42].

According to Song [33], communication in the metaverse bounces between the real and virtual worlds. The individuals can communicate physically in the same space and concomitantly interact from different worlds, moving from online to offline environments and vice versa, adding complexity to the process.

In education, the concept of skeuomorphism—combining, in the virtual world, objects and environments that are similar to those in the physical world—can be used to enhance the educational experience, allowing for the design of a very personalized metaverse, thus creating the illusion that teachers and students are in the same real/physical space [16]. Therefore, given the potential advantages of the metaverse, its use in education is likely to be widespread in the near future [43].

The use of the metaverse specifically in the educational context is discussed in the next sections.

4. The Metaverse and Education

The metaverse and education—and, particularly, higher education—are intertwined to the extent that, in contemporary education, they are always digitally mediated; students share virtual spaces, methods, and content that enhance both their academic and personal development. However, there are many skeptical voices about the relevance of the metaverse in education, believing that it can be misleading in terms of improving the educational process [37].

However, other authors, such as Tlili et al. [24] and Yue [37], for example, maintain that the metaverse contributes to enriching the educational process, including the teacher-student relationship, which, through the metaverse, has no barriers in terms of time and space. Moreover, the metaverse is fundamental to changing the classic educational model, which is traditionally static, to a dynamic model by mobilizing a wide range of situations, methods, tools, and forms of learning and assessment and placing the student at the center of the educational process, which potentially increases their motivation for learning [24].

Thus, according to Damar [19], higher education institutions should strive to incorporate topics related to the metaverse in their educational processes, such as virtual reality, augmented reality, simulation technology, 5G networks, artificial intelligence, cloud computing, 3D content creation, and blockchain technology, among others, as a way to better prepare their students and equip them with knowledge and skills that enable them to successfully face the challenges and demands of the labor market, with a more appropriate and redesigned curriculum [44]. These skills, not only technical but also soft or transversal skills, include complex problem-solving, adaptability, creativity, leadership, proactivity, critical thinking, creativity, teamwork, coordination with others, emotional intelligence, judgment and decision-making, service orientation, negotiation, and cognitive flexibility [10,45].

5. Changes in Education

Kye et al. [11], acknowledging an increasing convergence between these four dimensions, define the four types of the metaverse (augmented reality, lifelogging, mirror world, and virtual reality), which, for the purpose of analysis, seem highly relevant, as it is an instrument that enhances the heuristic capacity to grasp, in a more global way, the relationship between education and the metaverse. While these four types of metaverse were initially developed as independent of each other, they eventually evolved toward their convergence and interaction [11]. Table 3 details the four types of the metaverse as defined by Kye et al. [11].

Table 3. Four types of the metaverse.

	Augmented Reality	Lifelogging	Mirror World	Virtual Reality
Definition	Building a smart environment by utilizing location-based technologies and networks	Technology to capture, store, and share everyday experiences and information about objects and people	It reflects the real world as it is, but integrates and provides external environment information	A virtual world built with digital data
Features	Building a smart environment using location-based technology and networks	Recording information about objects and people using augmented technology	Virtual maps and modeling using GPS technology	Based on interaction activities between avatars that reflect the user's ego
Applications	Smartphones and vehicle HUDs	Wearable devices and black boxes	Map-based services	Online multiplayer games
Use cases	Pokemon Go, Digital Textbook, and Realistic Content	Facebook, Instagram, Apple Watch, Samsung Health, and Nike Plus	Google Earth, Google Maps, Naver Maps, and Airbnb	Second Life, Minecraft, Roblox, and Zepeto

Source: Adapatexd from Kye et al. [11] (p. 3).

Each of these types of metaverse has distinct technical/technological characteristics and also different implications in the educational context, presented in Table 4.

Given the above, it is essential to analyze the roles the metaverse plays in existing teaching, learning, and assessment processes, designs, and strategies in education [46]. According to these authors, the use of the metaverse in educational processes offers both students and teachers the possibility to experiment with new and innovative approaches and forms of teaching and learning, as well as to interact with the academic community, including by emulating the real world through virtual reality [46].

Table 4. Main technical/technological characteristics of the metaverse and educational implications.

Type	Technical/Technological Characteristics	Educational Implications
Augmented reality	- Overlay virtual objects in the real world to cause the object to seem 3D and real (e.g., paper birthday cards are augmented to appear as 3D video cards) - Adding fantasy to the thread (e.g., Pokémon Go on the street and Zepeto, which recognizes faces and creates 3D avatar) - Effectively emphasizing information and promoting convenience (e.g., HUD presented on the car glass)	- Learn invisible parts visually and 3-dimensionally through virtual digital information and effectively solve problems - In-depth understanding of content that is difficult to observe or explain in text and learners can construct knowledge through experience - Interactive experiences such as reading, writing, and speaking are possible while immersed in the learning context
Lifelogging	- One's daily life and thoughts are productively turned into content and shared through social media and SNS (e.g., blogs, YouTube, Wikis, etc.) - - Network technology forms relationships with others online, communicates quickly, and records various social activities (Facebook, Band, Twitter, etc.) - Personal activity information is accumulated and analyzed through various sensors of the internet of things and wearable devices to create added value (e.g., health tracking including Nike Plus)	- Review and reflect on one's daily life, improve the ability to represent and implement information in an appropriate direction, and feedback from others on social networks leads to reinforcement and rewards - Critically explore various information on the lifelogging platform and creatively reconstruct information through collective intelligence - Reflect on learning and improve it based on analytics data related to learning (e.g., dashboard) - Teachers promote learning in a customized direction based on students' learning log data, provide appropriate support, and prevent dropouts
Mirror world	- Expanding the real world by combining GPS and networking technology (e.g., Google Earth, various map applications, etc.) - Implementation of the real world into the virtual world as if reflected in a mirror for a specific purpose (e.g., Airbnb, Minerva School, food ordering app, taxi call, bus route guidance, parking lot finder app, etc.) - However, it does not contain everything in reality. In other words, it effectively expands the real world to increase the fun and playfulness, flexibility in management and operation, and collective intelligence (e.g., Minecraft, Upland, Digital Lab, etc.)	- Overcoming the spatial and physical limitations of teaching and learning, learning occurs in the metaverse of the mirror world - Conduct online real-time classes through online video conferencing tools and collaboration tools (Zoom, WebEx, Google Meet, and Teams), which are representative mirror worlds - Through the mirror world, learners can realize "learning by making" (e.g., in Minecraft, students build and restore historical structures—Bulguksa, Gyeongbokgung, Cheomseongdae, Taj Mahal, Eiffel Tower, etc. Users can experience their digital heritage and deepen their understanding of history and culture

Table 4. *Cont.*

Type	Technical/Technological Characteristics	Educational Implications
Virtual reality	- Through sophisticated computer graphics work, especially in a virtual environment implemented with 3D technology, users enjoy various games through a seamlessly connected interface (e.g., various 3D games including Roblox) - In a space, era, or culture and with characters designed differently from reality, they act as avatars rather than their original selves and have multiple personas - Chat and communication tools are included in virtual reality to communicate and collaborate with AI characters and others (e.g., multiplayer online games)	- Practice can be performed through virtual simulation in environments that are difficult to produce due to high costs and high risk (e.g., fire scenes, flight control, dangerous surgery, etc.) - Users can have immersive experiences of times and spaces that cannot be experienced in reality, such as the past or future - Through 3D virtual world-based games (according to the characteristics and types of designed games), users improve strategic and comprehensive thinking skills, problem-solving skills, and learn skills necessary for the real world

Caption: 3D, 3-dimensional; HUD, head-up display; SNS, social networking service; GPS, Global Positioning System; and AI, artificial intelligence. Source: Adapted from Kye et al. [11] (p. 8).

Hwang and Chien [46] argue that there are several relevant advantages and potentials of using the metaverse in education, as shown in Figure 3.

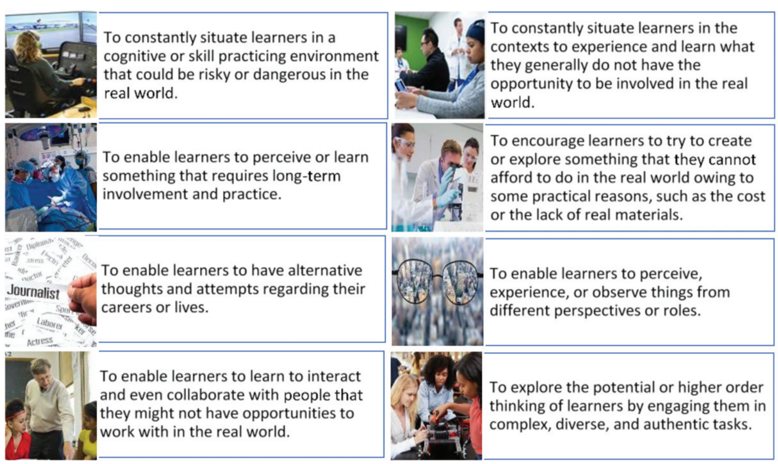

Figure 3. Reasons for adopting the metaverse for educational purposes. Source: Adapted from Hwang and Chien [46] (p. 3).

The metaverse classroom is very different from the traditional one, in that it is a virtual space equipped with digital resources and tools shared by teachers and students and is where physical and virtual reality are interwoven [41]. The visible advantages it has for the teaching and learning process cause it to be an increasingly used tool in educational institutions and incorporated into the curriculum [44]. It is what Wu and Gao [47] (p. 1082) call the "Edu-Metaverse", which the authors define as the metaverse applied to education. In this virtual scenario, educational actors are assigned digital identities and, through the use of information technologies, such as virtual reality, augmented reality, the internet of things, and blockchain, for example, interact in formal and informal teaching contexts in the virtual world. This allows for overcoming some of the barriers that traditional teaching and learning venues face, such as time and space, while actors have the possibility to learn both physically and virtually in an open and shared space, as well as increase participant motivation [16]. These new tools offer a world of new possibilities to both teachers and students to enrich the teaching and learning process, as "Schools and students can carry out virtual extracurricular activities and teaching practices through virtual museums, libraries, museums, science and technology museums, etc., which [...] achieves students' comprehensive and healthy development" [47] (p. 1083).

According to Zhang et al. [16] (p. 11), there are specific contexts that further value the application of the metaverse to virtual experiments, such as:

1. To assist the experiments that could be risky, irreversible, or toxic in the real world, e.g., an experiment with a potential risk of explosion;
2. To assist the experiment conditions and scientific phenomena that could not be possible in the real world, e.g., an experiment that needs to be carried out in a vacuum;
3. To assist the experiments that need relatively high costs and funds in the real world, e.g., an experiment that needs expensive equipment and materials;
4. To assist the experiments that react slowly or need long-term observations and records in the real world, e.g., an experiment needs learners to observe and record the whole growth stage of an insect.

With this new educational approach, the classroom is just one of many places where learning occurs because, through the metaverse and its use in education, anyone can attend a class, a lecture, or a seminar without having to be in the physical place where it occurs but from virtually anywhere in the world and in real-time. This dramatically increases the possibilities for everyone but especially those who encounter more obstacles in accessing education to develop their knowledge and skills faster than ever before [37].

Dwivedi et al. [48] divide the applications of the metaverse into two categories: (1) the metaverse as a tool, i.e., in cases where the metaverse is used to solve situations in the real, physical world; and (2) the metaverse as a target, i.e., how the metaverse can be used to develop and generate profits, among other things (Figure 4).

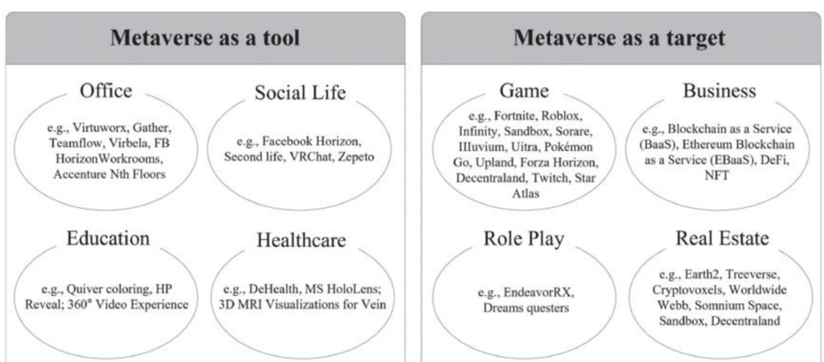

Figure 4. Applications of the metaverse as a tool and as a target. Source: Dwivedi et al. [48] (p. 5).

While, in its earlier stages, the metaverse was used mainly as a tool to address and solve problems in the real world (through digital applications and programs used in contexts such as work, education, social life, or healthcare, for example), it has now evolved to being used as a target, meaning that the metaverse itself, through new and improved digital applications and programs, can "[...] perform actions such as developing the metaverse and generating profits" [48] (p. 7).

In terms of the application of the metaverse to education, Dwivedi et al. [48], in line with other researchers [49], also argue that educational actors, namely teachers and students, can interact in the virtual world, which mimics the real, physical one. The research conducted by Dwivedi et al. [48] (pp. 36–37) allowed for reaching five relevant propositions about the importance of using the metaverse in education:

Proposition 1. *The use of metaverse in education should mirror the real-world learning environment for learners and educators. The metaverse can extend the forms of learning by providing learning opportunities that would not be possible otherwise.*

Proposition 2. *The use of metaverse can better facilitate new forms of training and go beyond the capabilities of the physical classroom and e-learning platforms combined.*

Proposition 3. *Educators need to elevate their pedagogical methods and course syllabus to accommodate teaching in the metaverse.*

Proposition 4. *New metrics need to be developed for evaluating learning experiences in the metaverse.*

Proposition 5. *Education providers need to offer new technical equipment and train educators on how to serve their learners in the metaverse.*

The authors maintain that the introduction of the metaverse in education represents a huge change in current teaching and learning processes and in the interactions between teachers and students, who are now able to maintain a relationship independent of time and space, using virtual spaces for teaching and learning, to bring innovation to educational processes and to extend learning opportunities [48].

In addition, in a metaverse, learning mobilizes their full potential:

> [...] there are two forms of teachers and peers that learners can interact with: one is avatar teachers and peers, and another is intelligent NPC teachers and peers. On one hand, through interaction with teachers and peers in the form of avatars or intelligent NPCs, learners can get more emotional support and real-time feedback instead of just looking at a grid of faces or boring slides on video-conferencing platforms. On the other hand, intelligent NPC teachers and peers can help to implement learning activities and give personalized support during class or after class. Social constructivism has emphasized that an individual's knowledge is constructed through social interactions [...]; hence, it could be a reason for using the metaverse in education for the cognitive and social development of learners [16] (pp. 7 and 9).

It is interesting to note that NPCs (Non-Player Characters) originated within the context of computer games, consisting of a character controlled by the computer, rather than the player [50]. This concept has been applied to the metaverse-based learning environment, namely in terms of intelligent NPC teachers, intelligent NPC learners, and intelligent NPC peers, all of whom play a pivotal role in "[...] supporting arbitration, simulation, and decision-making for educational purposes" [16] (p. 6). The use of NPCs in education enables addressing personalized needs and eases the interaction between students and teachers [16].

6. Challenges

One of the main advantages of using the metaverse in education is that it allows all people around the world (provided they have the technical conditions) to access education without being constrained by physical barriers [37].

As with the emergence of any new technology, there are different perspectives on the metaverse [51] applied to education, some positive and others a little more reticent [13]. Yue [37] argues that the interaction between teachers and students will change completely, as will the ways in which education is delivered to students. Education will be democratized and accessible to all, regardless of their economic, cultural, or social background. Conversely, Floridi [22] (p. 7) expresses his concern that the "digital divide will increase rather than decrease" with the use of the metaverse in education, as not all individuals have equal and adequate access to what he calls the extended experience and many may be left out. Mistretta [10] is also skeptical about the complete replacement of face-to-face learning with virtual learning while acknowledging its importance in providing teachers and students with a space where educational experiences can happen in a hybrid format.

The metaverse applied to education can be an excellent way to help a special group of individuals such as those with autism spectrum disorders (ASD), those with social anxiety disorders, and those with physical disabilities, for example [9,14,52]. These individuals have, in this new educational setting, the opportunity to learn various social skills and to grasp the learning opportunities created by the metaverse. In this regard, Gülen et al. [53] argue that virtual freedom in terms of time and space can help education become more inclusive and foster participation for all, particularly students who have disabilities:

> The learning analysis module aims to utilize massive data to analyze and display learners' learning performances and achievements by unit or in all. More significantly, it can make assessing learners' performance easier, and provide teachers with reliable proof to conduct personalized services for learners [16] (p. 7).

The opportunities for using the metaverse environment to improve the quality of education are numerous. Gülen et al. [53] provide a good example of such an opportunity in the field of STEM (Science, Technology, Engineering, and Mathematics) studies. The authors maintain that this environment "[. . .] will provide the development of cognitive, affective, and psychomotor skills for the learner. [. . .] will improve cooperation and teamwork. [. . .] Virtual classrooms will facilitate access to hard-to-see experiments and applications. [. . .] will provide a modelling opportunity. [. . .] will provide equal opportunity for disadvantaged groups" [53] (pp. 101–102). The authors further comment that the application of the metaverse to STEM education has challenges, namely in terms of the necessary equipment, software, internet structure, legal ambiguities, and potential disconnection from the physical world [53].

In the same vein, Kye et al. [11] (p. 10) draw attention to the fact that while the metaverse has great potential in education, it also has some shortcomings that need to be addressed. The line between the real and virtual world becomes more blurred, which can cause some confusion among users regarding their "'real me' identity". Thus, the authors present the main characteristics of the metaverse, along with its merits and weaknesses when applied to education (Table 5).

Table 5. Characteristics of the metaverse and the merits and shortcomings in its educational applications.

Metaverse Characteristics	**Merits**	**Shortcomings**
New social communication space	Even in the case of school closures due to coronavirus disease 2019, students can socially connect beyond the limitations of reality	When forming a relationship with others, one forms a relationship centered on play that is weaker than interaction in the real world; privacy problems occur due to the collection and processing of various pieces of personal information
High degree of freedom	Expanding student autonomy in the learning process by providing experiences from content consumers to creators	Due to the high degree of freedom, platform administrators cannot predict all the actions of users and they can be exposed to various crimes due to the virtual space and anonymity of the metaverse
Through virtualization, high immersion	By providing a new experience that transcends time and space, it is possible to increase student interest and immersion to expand students' active participation in learning	It can cause identity confusion, escape from reality, and maladaptation to the real world for students whose identity has not been established

Source: Adapted from Kye et al. [11] (p. 11).

Furthermore, Wu and Gao [47] warn about the risks that the so-called "edu-metaverse" entails. The authors mention the following as the most important:

i. There is no high-level design or systematic planning and explicit development goals in terms of implementing the metaverse in education;
ii. There is a lack of theoretical and applied research in the field of the edu-metaverse, i.e., the educational products used in the edu-metaverse environment are not sufficiently based on systematic and scientific theoretical support in the educational field.
iii. There is a risk of ethical issues arising from the use of the edu-metaverse, as data as information about individuals is easily accessible and is used for unethical purposes. On the other hand, the sources of data and information are increasingly complex, which may lead to issues of trust on the part of users. In addition, and perhaps most importantly, the edu-metaverse is highly immersive and interactive, which can present a real risk of addiction for students.
iv. There is a risk of capital manipulation, inasmuch that under the general consideration that the edu-metaverse can reduce the existing education gap, it is critical to analyze whether capital can be the edu-metaverse and thus impede educational equity and perpetuate the digital divide [47].

It is a fact that, as a metaverse, its use in education and the construction of virtual identities have several benefits, but this scenario is not without disadvantages. The thin line between real and virtual identities and the still low support, both technically and financially, for the construction of virtual identities can hinder the communication process [13,33]. This process has the potential to combine the real and virtual worlds to prevent students from becoming totally disconnected from the real world, "[...] losing their due judgment and self-knowledge, and causing the deviation of thought and behavior" [54] (p. 7). However, a good deal of risks emerge in both metaverse and virtual environments, which stem from digital technologies, such as the issue of "[...] privacy, abuse such as bullying or virtual violence, computer crimes, cyber-attacks, vandalism and hacker attacks, or how ransomware and pornography might develop" [22] (p. 6) or "[...] problems of addiction and escape from reality generated by the Metaverse" [22] (p. 7). Jiaxin and Gongjing [35] also point out that although the metaverse applied to education enhances the teaching and learning process, it may entail ethical issues, namely in terms of privacy, cyber-bullying, and deceiving educational inequalities. The avatars created in this virtual environment are a further challenge, as there is no consensus on whether the real individual is the source of the avatar's actions and behaviors or whether the real individual assigns the avatar a new role [46].

On the other hand, potential legal issues may also arise with the use of the metaverse, namely "[...] data protection and privacy, intellectual property rights and personal harm" [55] (p. 490).

The use of metaverse has direct implications and consequences for the individual's privacy and entails security and ethical risks [11,39,40]. The data produced or searched online can be traceable, whether it is active or passive data. The former is produced when an online user actively clicks, comments, or forwards any piece of information on a particular online platform. The second concerns the personal information that users unintentionally leave on an online platform, such as their geographical location, social relationships, voices, and faces, notwithstanding the "user informed consent" present in many platforms, thus increasing the potential risks and dangers of metaverse use [34,56].

In their comprehensive review of the various educational use cases of the metaverse, Jagatheesaperumal et al. [56] provide a summary of the different educational scenarios, the challenges each faces, the intended goals and countermeasures to address the challenges emerging from metaverse-based education/training in different fields (Table 6).

Table 6. Metaverse enabled education, training, and skill development. Challenges and countermeasures.

Application	Challenges	Goal	Countermeasures
Healthcare education	Handling multi-modal medical data and streamlining	Innovative drive in medical education	New directions to the healthcare education sector could be driven through the integration of metaverse with AI, VR, AR, IoMT, Web 3.0, intelligent edge, cloud services, robotics, and quantum computing
Online education	Collaborative efforts and interactions	Immersive experience for teachers and students	Appropriate choice of XR and IoE equipment with dedicated seamless connectivity targeted for meeting the demands of the teachers and learners
Industrial training	Training robots and skill enhancement for labors	Monitor and control complex manufacturing units	Binding the hardware and software components of metaverse in the manufacturing, supply chain, design, development, and virtual warehousing to drive the market revenue and forecast the impact of technology over the next few years and make decisions accordingly
Aircraft maintenance training	Maintenance, status monitoring and control	Intuitive and efficient control of functional modules in aircraft	3D twin models of aircrafts help to read the aircraft log books and records, which includes the entries of the condition of the internal equipment, status, and intimates the requirements for the learners and users in the remote place
Marine maintenance training	Handling of cybersecurity issues	Robust defense mechanisms against treats	Integration of metaverse with blockchain based technological trends, helps to reduce errors in maintenance tasks with secured means of handling the challenges with increased safety through alerts and notifications
Military training	Replicating the war scenes and dynamic adaptation	Trained to face adverse conditions	Improved productivity with clear instructions through metaverse driven equipment for dynamic handling of war situations
Art upskilling	Managing 3D virtual objects	Imagination and creativity to reality	Enhanced quality and accuracy with object recognition for immersive learning with applied creativity beyond the imagination
Gaming expertise	Integration of AI for provisioning immersive experiences	Collaborative learning	With unified and interoperable spaces rendered through the graphics, interaction with the people and objects in the virtual worlds causes the gaming platform to have incredible potential in using the metaverse for provisioning a diversified range of education, training, and skill development applications

Source: Adapted from Jagatheesaperumal et al. [56] (p. 12).

In sum, for the various fields of education/training, the achievement of each immersive learning objectives through the metaverse implies the need to address challenges with appropriate countermeasures [56].

In the context of the COVID-19 pandemic and the need to move from face-to-face teaching and learning to online teaching and learning at all levels of education, one of the critical issues that emerged was teachers' digital literacy. Tlili et al. [24] maintain that this is the best-prepared generation to use and interact with the metaverse educational environment and technologies, although there is still a lack of research to support this assumption. On the part of students, Talan and Kalınkara [43] maintain that they welcome this new educational approach because of its many advantages. Yet, the authors warn of the disadvantages of using the metaverse for educational purposes, such as the difficulty and distraction on the part of some students and their disconnection from the real world.

For all this, it is crucial to carefully weigh the advantages and shortcomings of using the metaverse in the educational environment. First and foremost, it is paramount to understand the students' views and uses of the metaverse, their levels of immersion, and the effects on their learning.

On the other hand, being a virtual world, the metaverse allows individuals to have experiences that they would not otherwise have in the real world, but this may lead to an uncritical acceptance of the content and products offered, which may or may not be suitable to students' needs and/or competencies. Thus, both content and product designers and teachers need to analyze whether what they offer/work on is in line with what students expect so that the teaching and learning process can be fruitful and meaningful for the students [11].

When used correctly, the metaverse applied to education can contribute not only to the achievement by students of hard skills (of a more technical nature) but also of soft or transversal skills [45] and digital skills [57], both of which are highly relevant in the contemporary labor market.

As with anything new, especially in education, caution is needed when using the metaverse in this environment [16]. It is crucial to analyze how students with different personal characteristics see, respond to, and benefit from this new learning context [46]. Wang et al. [49] (p. 5) caution that this new educational approach, characterized by being "[. . .] more student-centered, collaborative and innovative" has to be carefully analyzed and designed to fully utilize its potential and mitigate its drawbacks.

7. Conclusions

The possibility of transforming the university into a "metaversity" [36] (p. 12) through this transition with a greater centrality of the metaverse in the formative process, as a process with great uncertainties that is totally new, implies the participation and cooperation of several stakeholders.

The government of each country is paramount in leading and monitoring this process of building an educational system that has incorporated the metaverse, i.e., the edu-metaverse setting. In turn, companies that provide services or products related to the metaverse should intensify the research and development of all the technologies that form the basis for the operation of the metaverse, quickly and efficiently solve technical problems, and offer quality services. In addition, these companies should implement the complete management of the data resource chain and permanently improve the supervision and control mechanisms and interact closely with educational institutions to constantly tailor the services they provide to their audience, i.e., the educational community. Furthermore, the general public should make efforts to be more aware of both the potential and the risks of online networks [47].

The metaverse is still a novelty concerning its use in educational settings. As such, there is a need to intensify support and encouragement for its use in educational institutions, as well as to provide platform training through the cooperation of higher education teachers, teaching, and learning centers and other related entities [21].

In any case, there is a need for further empirical and theoretical studies on this topic [10,16,24,43,46], but always keeping in mind that there are several elements that need to be considered when using the metaverse for educational purposes:

> [. . .] first, teachers should carefully analyze how students understand the metaverse; second, teachers should design classes for students to solve problems or perform projects cooperatively and creatively; third, educational metaverse platforms should be developed that prevent misuse of student data [11] (p. 1).

Above all, it seems to us that the most important thing will be not to run the risk of being more concerned with virtual reality than with the real one [22].

The use of the metaverse in education is just beginning its first steps and, thus, its users will find many benefits but also many pitfalls arising from its use, especially at a time when research on this topic is still scarce and people lack adequate training to properly use the metaverse in education [24]. Therefore, and for now, educational institutions and students should be cautious and aware of the good and the not-so-good sides of the metaverse.

As with all studies, this one also has limitations. Given that this is a rather emergent topic, there is no substantial prior research, which caused it to be more difficult to find quality articles, books/book chapters, or conference presentations that drew on the topic under analysis.

Furthermore, while seeking to follow the rules for performing a sound literature search [58], such as using more than one international comprehensive database, it is possible that a search in other databases would provide more studies that would further enhance this research study.

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education sciences

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Review

Reconceptualising Disabilities and Inclusivity for the Postdigital Era: Recommendations to Educational Leaders

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Abstract: Inclusive education is pivotal to sustainable development in different parts of the world. This perhaps accounts for its inclusion in the Sustainable Development Goals (SDGs) in SDG4, which targets inclusive education. Meanwhile, inclusive education has predominantly dimensioned physically challenged or impaired learners. However, with the outbreak of the COVID-19 pandemic and the sudden transition to online teaching and learning, the quest for a different dimension of inclusive education, especially with regard to technology, is on the increase. This paper investigates how inclusive education is presented in scholarly published articles in the South African context. Five phases of a scoping review, namely, identification, finding/searching, choosing, extraction/charting and collation, were adapted for the review. From a search using the terms "inclusive" AND "distance" AND "education" AND "disability" AND "South Africa", a corpus of 73 scholarly published articles was identified. Using different selection criteria, such as specific context of the review, 55 articles were deleted. Thus, a final corpus of 18 articles was analysed. From the reviewed relevant literature, themes were generated after retrieved information had been coded and categorised. The review indicated that the focus on inclusive education in the South African context is directed towards physically impaired or challenged persons. The paper recommends that in the context of distance education and with the sudden transition to online teaching and learning, lack of access to technology such as computers and Wi-Fi, among others, can constitute a technological disability. Thus, inclusive education in the dimension of technological disability should be explored to enable the leadership of education systems in providing the required assistance.

Keywords: disability; inclusive education; inclusivity; technology use; scoping review; South Africa

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1. Introduction

Transforming the higher education sector in alignment with "the South African Constitution has led to increased enrolments of learners with disabilities" [1] (p. 18). Similarly, Isaacs (2020) [2] states that "over the last four decades, increasing numbers of disabled learners have entered institutions of higher education worldwide. Since 1994, the South African Government has been committed to transforming educational policy to redress the past oppression of disabled persons" (p. 58). This suggests following the long history of apartheid in South Africa prior to 1994, the extent to which the nation attempts to cater for persons with disabilities and ensuring inclusivity in the higher education sector. Additionally, it can be viewed from the perspective of the nation attempting to follow the Sustainable Development Goal (SDG) 4 of the United Nations (2015) [3], which is targeted at ensuring inclusive and equitable quality education and promoting lifelong learning opportunities for all. In the South African context, McKenzie and Dalton (2020) [4] (p. 1) states that "South Africa has undertaken the implementation of inclusive education as a vehicle for achieving enhanced educational outcomes and equity". This is indicative of the extent to which inclusive education is embraced and upheld in the nation. In congruence, [5] emphasize that "the policy of inclusion is one of the key policies enacted by the Department of Education in South Africa since the demise of apartheid" (p. 561). In furtherance, from a historical point of view, McKenzie and Dalton (2020) [4] (p. 1), citing [6], state that " . . . with the advent of democracy in South Africa, issues of curriculum change and provision of quality education to all children of all race groups assumed a high priority, largely because of the preferential treatment of white children under apartheid". McKenzie and Dalton (2020) [4] further state that "an overhaul of the entire education system was undertaken, and this included a reconsideration of special education and educational support" (p. 2). In South Africa, although schools as well as educators in the context of this review are doing their best to ensure inclusivity in education, certain challenges tend to affect efforts made [7]. However, Morrison, Brand and Cilliers (2009) [8] earlier stated that "dealing with the special needs of learners with disabilities brings new challenges to institutions" (p. 202). This suggests that while challenges are being resolved, there are tendencies for more to emanate. Thus, schools which aim at receiving recognition for more inclusivity need a proactive approach which cuts across the entire institutional environment [8].

1.1. Factors Hampering Inclusivity in Schools

Sequel to reviewed literature, some factors were identified as affecting inclusivity in education. These factors may be relevant to other related areas in the field of education, however, in the context of this review, the focus remains on inclusivity in distance learning. The factors are:

- Institution's non-awareness of the existence of learners with disabilities and/or inability to identify such learners due to lack of clear procedures [9];
- Inability of learners with disabilities to access learning materials [9];
- Learning barriers experienced by learners [10];
- The physical structures of schools or access to campus locations [8];
- The adopted approach of teaching, assessment and information dissemination [8];
- Socio-cultural or attitudinal climate defined by mainstream learners and staff [8] (p. 202);
- Lack of support from stakeholders such as parents, negative attitudes from learners', as well as examination and result-oriented systems [5];
- Lack of motivation, learners' negative thoughts and feelings towards certain subjects considered difficult, and learners' state of being disengaged [11];
- Academic faculty's lack of knowledge on how to facilitate inclusive learning [12];
- Limited resources or lack of resources or infrastructure and time [7,13–15].

1.2. Factors Promoting Inclusivity in Education

Review of the work of [16] indicates that certain factors are capable of ensuring inclusivity, especially in the context of a physically impaired or challenged student. The identified factors may be relevant to other related areas in the field of education; however, in the context of this review, the focus is on inclusivity in distance learning. Among the factors are the following:

- Availability of tutors capable of committing a large amount of time to help learners understand content presented in class;
- Quality tutorials;
- Quality practical sessions;
- A well-resourced and effective disability unit;
- Educators who will ensure that learners are well accommodated in class, tutorials and practical sessions. For instance, Lourens and Swartz (2020) [17] state that "despite stringent policies, educators still have the power to decide whether they want to accommodate learners with reasonable requests" (p. 320). This suggests that educators have pivotal roles to perform in ensuring the success of physically challenged learners. In congruence, Zongozzi (2020) [9] reinforces the fact that in some instances in the South African context, educators lack the capability to support learners with disabilities, and this affects the learning abilities, as well as the academic performances of such learners);

- Learners' dedication and commitment to learn;
- Institution's awareness of the existence of learners with disabilities and/or ability to identify such learners using clear procedures [9].

The foregoing shows efforts made in embracing and promoting inclusive education regardless of the promoting and demotivating factors. However, with the turn of events due to the COVID-19 pandemic, following the sudden transition to online teaching and learning, a new type of inclusivity in education is to be demanded as different learners seemed to have been left out [18]. For instance, according to [19] making reference to the work of [20], "a COVID-19 rapid-response survey of 98 countries around the world discovered that higher learning institutions began teaching online through a variety of platforms such as television and radio broadcasting of lessons, and putting in place innovations such as socially distancing proof hubs and centers" (pp. 140–141).

De Klerk and Palmer (2021) [13], alluding to the work of [14], state that "the acquisition of digital literacy skills became difficult to fully pursue and, given the restricted resources and time, constant digital challenges morphed into new forms of educational inequalities" (p. 13). Meanwhile, focus, in terms of inclusivity in education, continues to linger around people mainly with physical disabilities, leaving out other marginalized persons due to lack of technology savvy. Hence, the reason for this review is to investigate the subject of inclusivity in distance education from the dimension of technology use, in the context of South Africa and possibly by extension developing and underdeveloped countries of the world where access to technology remains a struggle. The review is guided by the research question: What is inclusivity in distance education from the dimension of access to technology, technology disability and skills? The remaining part of the article is sectioned as such: contextualization of terms, the materials and methods adopted in the review, otherwise called 'the protocol' in a scoping review, results, discussion, and conclusion.

1.3. Contextualization of Terms

1.3.1. Inclusion

This is described by scholars in different ways. For instance, Moleko (2021) [11] views inclusion from the point of view of educators ensuring that learners are carried along when teaching specific subjects which are consider difficult and tend to be demotivating. Malebese, Tlali and Mahlomaholo (2019) [15] view inclusion from a social context. In other words, learners are to be integrated into the teaching and learning environments using social strategies. According to [21], the best results can be achieved when institutions of learning have the authority to formulate their own way(s) of practicing inclusion in their approaches to teaching and learning. In the context of this review, inclusion is considered from a technology standpoint; hence, it is used to mean ensuring that all learners are carried along with the advancement of technology and transition of teaching and learning from onsite to online. This is regardless of their location, which can be rural or urban, and socio-economic status, among other factors.

1.3.2. Postdigital Era

A postdigital era according to author [22] implies a period when technology use will be highly upheld and considered as the standard norm for achieving tasks. During this era, blended learning is envisaged to be experienced more in different parts of the world compared to what is currently obtainable [23–25]. In the context of this review, postdigital is seen as an era that there would be more concern for human beings than technology. It is similar to the perception of being "undigital" that is a case where society and technology advance beyond the limitations of digitalization in order to attain a completely fluid multimediated reality. This reality is envisaged to be void of digital computation artefacts. Postdigital era in this study is one that is concerned with fast changing relationships between humans and digital technologies.

1.3.3. Disabilities

From the reviewed literature, disabilities common in institutions of learning which are to be taken into cognizance can be viewed from three perspectives: (1) auditory [26]; in furtherance, Isaacs (2020) [2] explains that there is a need to consider and include stuttering learners as one of those in the category of auditory disabled persons, so they should be catered for; (2) mobility [26–29], and (3) visual [26,29–31]. In this review, disability is viewed from the perspective of learners being incapable to learn due to lack of technological gadgets or skills to operate such where available.

2. Materials and Methods

A qualitative method was adopted for this review. Content analysis was used in analysing the retrieved articles. Luo (2021) [32] (p. 1) states that "content analysis is a research method used to identify patterns in recorded communication". Hsieh and Shannon (2005) [33] hold the view that content analysis is widely used in qualitative research as a technique. In congruence, Columbia University (2019) [34] reports that "content analysis is a research tool used to determine the presence of certain words, themes, or concepts within some given qualitative data" (p. 1). However, in contrast, Luo (2021) [32] states that content analysis can be qualitative or quantitative. Thus, in this review, qualitative content analysis was adopted. Meanwhile, according to [35] (p. 69) and reported in [36], "there is no single right way to do content analysis. Instead, investigators must judge what methods are appropriate for their substantive problems" (p. 73). Thus, in this regard, content analysis is used in this scoping review. On the other hand, according to [37], a scoping review is predominantly conducted in order to identify existing gaps in an ongoing research and highlight different areas which demand additional probing. In this review, inclusive education with reference to technology as a major constraint and demand in the South Africa context is viewed as a subject which needs further probing. This is due to the fact that disability in inclusive education is majorly viewed from the point of physically challenged individuals, whereas in distance education, especially in the context of South Africa, disabilities can be viewed from access to technological gadgets and skills needs in the use of technology in teaching and learning in distance education. Content analysis was also adopted for the study in alignment with the adopted review method. Romund (2017) [37] reporting for the University of Manitoba, Canada, highlights five phases that are crucial and to be followed when conducting a scoping review. These phases which can be considered as steps are similar to the six stages recognized and adopted by [38] as well as [39]: identification of the research question(s), identification of relevant studies, study selection, charting the data, and collating, summarizing and reporting results, consultation exercise which is described as an optional stage. However, for the purpose of this study, the five steps put forward by [37] are followed. These are as explained below:

Step 1: Identification of the research question(s) as well as the domain which needs exploration. Following the submission of [37], and the position of other scholars such as [38] as well as [39], the researcher identified the research question guiding the study: What is inclusivity in distance education from the dimension of access to technology, technology disability and skills? The author considers the identified question as a domain which needs to be explored.

Step 2: Find (search) phase: Romund (2017 [37] in congruence with [38] as well as [39] states that having identified the research question of the study and domain which needs to be explored, there is need to find relevant studies using different electronic databases, websites, reference lists, conference proceedings, among others. For this study, search was performed on two databases known as Scopus and Web of Science (WoS). These two databases were selected following the submission of [40], which attributes them to being the big commercial, bibliographic databases for scholarly literature.

Step 3: Selection phase: At this stage, the researcher is expected to make choices of literature that are relevant to the identified research question(s). At this point, certain predetermined criteria are to be used for the inclusion of relevant articles and exclusion of those that are irrelevant. For this study, the search terms were: "inclusive" AND "distance" AND "education" AND "disability" AND "South Africa". Following the search, published articles and conference articles were included, while books and book chapters were excluded. The reason for the inclusion of published articles and conference articles was because of the review process involved in journal and conference articles. The researcher believes journal articles and conference proceedings go through rigorous review compared with books and book chapters. Furthermore, at this phase, the author eliminated certain articles which were considered irrelevant following certain criteria such as not having inclusive in the main text, likewise not being in the specific context of South Africa which is the focus of the study. Thus, articles which were in the context of South Africa and had inclusive in the main text, not necessarily reference list were included for analysis in the study. Figure 1 shows the flow chart which indicates the initial and final corpus of articles.

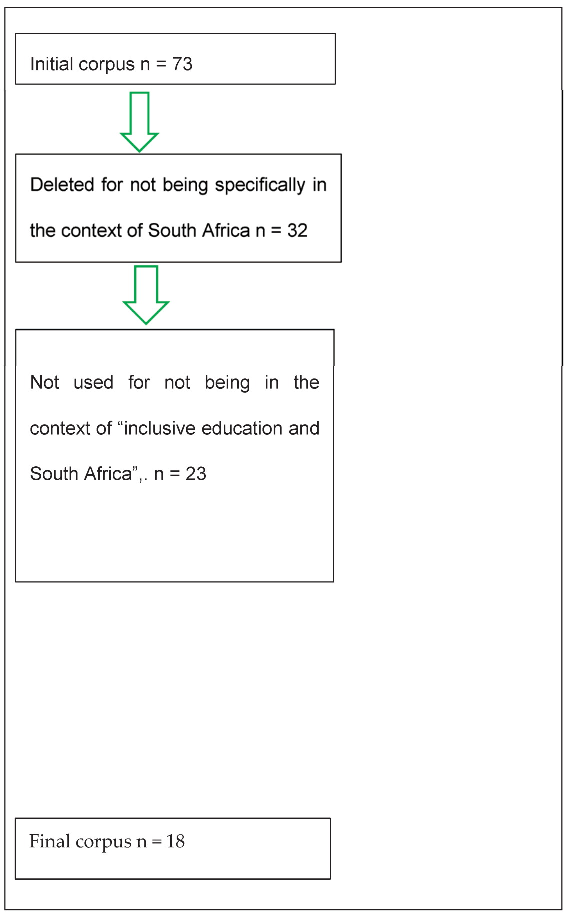

Figure 1. Searched articles and final corpus.

3. Results

The results of the study are as presented below following the explanation from findings presented in Figure 1. The figure indicates how certain articles were excluded before ascertaining the final corpus. For instance, following the initial search, a corpus of an initial 73 articles was retrieved and downloaded; thereafter, the author sieved them all. For not being specifically in the context of South Africa which is the focus of the study, 32 articles were deleted, and the author was left with 41 articles. Subsequently, the author further deleted 23 articles for not being in the context of "inclusive education, and South Africa" and for not having "inclusive" in the text but in the reference. Thus, final corpus of 18 articles were considered useful for the study for having 'inclusive' and being in the context of South Africa.

Step 4: Extraction and/or chart phase: At this stage, the data from selected relevant studies are to be organised. In the context of this study, the researcher organised the final corpus of 18 relevant articles into how inclusion in education is considered and presented in different articles by various scholars. In the analysis of the final corpus of 18 articles adopted for this study, inclusion was presented and explained in the context of persons with disabilities. In the other three articles, inclusion was presented in each of them in the following contexts: inclusion as per teaching a particular subject considered difficult; inclusion in the context of rural schools and learners into learning activities amidst the COVID-19 pandemic; and inclusion in terms of social context. Table 1 below presents a summary of the contexts in which inclusion was presented in the 18 analysed corpora.

Table 1. The analysed corpora.

Context of Inclusion	Number of Article(s)
Disabled people	15
Teaching perceived difficult subjects	1
Rural schools and learners into learning activities amidst COVID-19 pandemic	1
Social	1
Total	18

Step 5: Collation or summary phase: At this stage, the author summarizes the findings of the study. Sequel to the submission of [36], it is at this stage that the data can be coded, categorised, thereafter theme generated for explanation. Thus, in the context of this study, from the analysed final corpus of relevant literature themes were generated following the coding, and categorization from the submission of the scholars whose works were analysed. Each of the identified themes are presented and explained in the next section titled 'discussion'.

4. Discussion

The discussion is guided by the research question of the study: What is inclusivity in distance education from the dimension of access to technology, technology disability and skills? and the generated themes from the analysed relevant literature.

4.1. Theme 1: Inclusivity in the Context of Historically Disadvantaged (Black) Persons

Although the study did not set out to explore issues of inclusivity in the context of historically disadvantaged persons, this emerged as a major theme following the analysed reviewed relevant literature. This theme suggests how inclusion is perceived and upheld in the nation. This could be as a result of its long history and various experiences with regard to apartheid. The works of [5] as well as [4] suggest that inclusivity in education in the context of South African education system entails the quest for providing quality education to black (historically disadvantaged) children based on how they were excluded under the apartheid government. Ngubane-Mokiwa and Zongozzi (2021) [19] alluding to the work of [41], presents it from the perspective of inequality state that " ... the prevalence of inequalities in South Africa where previously disadvantaged students such as blacks, women, persons with disabilities, the rural and urban poor and adults who have missed out on opportunities to access higher education ... (p. 137, italics added for emphasis)". In congress, [5] citing the work of [42], state that " ... the decentralization of education provided racially defined communities the legal means to preserve their privileges that schools have been much more successful at meeting the demand for racial desegregation than achieving the ideal of social integration and that messages forthcoming from 'race' affect black learners more negatively than other learners in South Africa (p. 566, italics added for emphasis)". Meanwhile, [4] explaining that inclusivity should cater for 'Special needs' which are described as " ... not only issues of disability but also include issues of economic, social and linguistic contexts, ... (p. 2, italics added for emphasis)". According to [19], lack of inclusivity in education with regard to the physically disabled persons brings about marginalization. Thus, certain courses are considered impossible for people who are physically disadvantaged. "The field of Science, Technology, Engineering and Mathematics is a practical field that requires a lot of innovation and consideration ... to reasonably accommodate students with disabilities ... university not accommodating students with disabilities at the Science campus [19] (p. 145, italics added for emphasis)".

4.2. Theme 2: Inclusivity in the Context of Physically Challenged (Disabled) Persons

The final corpus shows that more of the retrieved articles were directed towards physically challenged people. A reason for the high number of 15 articles in the final analysed corpus which focuses on inclusivity education in the context of persons with disabilities can be attributed to the work of [2] which suggests the high increase in the number of disabled learners being granted access to higher education institutions across the globe. Additionally, in the South African context, the commitment of the Government in the transformation of the policy of education in redressing previous oppressions of persons with disabilities as alluded to by [2] could be an attributed reason for the high number of 15 articles in the final corpus of this study. Meanwhile, inclusivity in the context of technology in education can assist in enabling teaching and learning practices for the physically challenged people. " ... the application of COIL for students living with disabilities may transform their learning experiences and unlock new pathways for their development" [43] (p. 80). COIL which stands for collaborative online international learning. This suggests that while considering inclusivity in the context of technology in education in the postdigital era, the physically disabled would have been catered for.

4.3. Theme 3: Inclusivity—For Persons with Special Educational Needs (SEN)

Education is paramount for growth [44,45], it attempts to solve issues of inequalities as opportunities are made available to different people [46,47]. This is supported by [13] who state that "Education is broadly known as an indispensable apparatus for growth, a means of attaining equal opportunities, inclusion of the marginalized (p. 13, italics added for emphasis)". However, this is not so in some instances where marginalization is made to thrive. For instance, De Klerk and Palmer (2021) [13] report that "Scholars acknowledge that the notion of inclusive education has moved beyond uniquely referring to persons with special educational needs (SEN) to extend to all persons at risk of exclusion or marginalization in society (p. 17, italics added for emphasis)". This suggests that as important as education is and enhances growth, it can create some forms of marginalization. Thus, for such to be avoided, disability is to be considered from different points of views and consequently addressed. In other words, disability and the need for special education is to be explored beyond the group of people with physical disabilities. In other words, those in societies that are liable of marginalization in any form are to be considered also and duly assisted. In the context of this study, the case of people living in technologically marginalized areas with little or no internet connectivity, technological facilities, exposure, among others becomes paramount. For instance, according to [48], "In many countries, the heavy reliance on online learning and connectivity technologies to deliver education exacerbated learning inequalities because many governments did not have the policies, resources, or infrastructure ... (par. 14)". This suggests that while technology may be a useful tool in the attempt to fight and possibly eradicate inequality, it can be a source of marginalization, thereby widening the gap of inequality between the 'haves' and 'have nots'. Suffice to state that inclusivity with regard to technology in education is a major subject matter which needs the attention of education stakeholders in order to address issues of marginalization, inequalities, development, among others.

4.4. Theme 4: Way Forward

Sequel to the studies of different authors of the relevant reviewed literature, some findings made by scholars in the context of inclusivity as per historically disadvantaged persons as well as persons with physical disabilities are adapted. However, for this study, the author adapts some of the submission considered suitable for inclusivity in the context of technology. Ref. [5] suggests that " ... the Department of Education should adopt the inclusive model of [49]". The model is presented below. The author of this paper attempted to explore the model and consider ways by which such can be adopted with regard to inclusivity and technology in the postdigital era.

According to the model presented in Figure 2, six major steps are to be considered. These are: orientation training, expanding access to schools, curriculum development and assessments, provision of resources, national advocacy campaigns, revision of legislation and policies. Adapting these steps to inclusivity with regard to technology in preparation for the postdigital era, it implies that there is need for all stakeholders in education inclusive of students, academic and non-academic staff to be oriented on the importance of the inclusion of technology in teaching and learning, thereafter, trained towards being able to adopt and put such to practice. Additionally, access to schools needs to be expanded; moreover, with technology, this would be more visible. Thus, guided teaching and learning can take place without students and teachers being present in the same physical location. McConkey (2014) [49] further emphasizes the need for curriculum development and assessment. In the context of this study, it implies that the curriculum would need be designed to accommodate relevant practices, needs and designs in the postdigital era. Meanwhile, such curriculum would need be assessed periodically to ensure its relevance. Provision of resources is another crucial phase of the model. Technological resources would be needed for the desired goals to be achieved. Thus, education stakeholders would need to ensure that the necessary resources needed to drive inclusivity of technology in education are made available. This is because lack of such can hamper the designed curriculum as well as the entire process of education in the era. Additionally, there would be need for national advocacy campaigns which promote the inclusion of technology in education during the postdigital era. This would enhance possible acceptance from different people as well as support. Additionally, revision of legislation and policies is required [49]. This implies that different relevant legislations and policies are to be revised to accommodate the inclusion of technology in education. This is in congruence with the submission of [5] who state that in ensuring inclusivity, " ... teachers face challenges in their attempts to implement the policy of inclusive education in their teaching (p. 573)". Thus, teachers are to be assisted in ensuring the implementation of policy of inclusive education. Thus, following the context of this review, policy on inclusive education with regard to technology should be considered and teachers should be assisted to ensure its implementation.

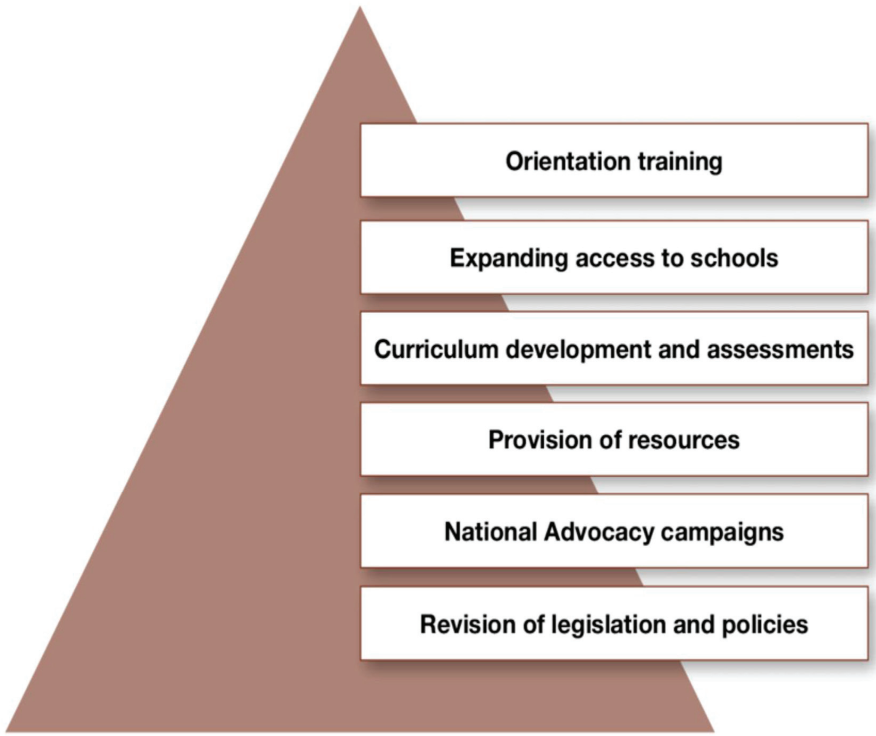

Figure 2. Key strategies for inclusive education [49].

From the foregoing, the paper indicates that whilst 18 articles were considered relevant for the review, none presents inclusive education in South Africa in the context of technology. This implies that there is paucity of literature with regard to considering inclusivity in education in the context of technology.

In contrast to the findings of this review, the work of (deleted to enhance the integrity of review) is suggestive that inclusivity in the context of education in South Africa is to also involve the technologically disadvantaged. In this regard, as emphasis is placed on policies of inclusive education and support provided are targeted towards the physically disabled and marginalized people due to the long history of apartheid in South Africa, the same is to be done for the technologically disadvantaged. Meanwhile, according to the submission of [22], technology is expected to be the major standard in the postdigital era. In the same vein, the findings from the works of scholars such as [23,24] as well as [25] show that technology has a pivotal role to play during the postdigital era. This suggests the need for inclusivity in the context of education to be reconsidered to involve and make provisions for technologically impaired learners.

5. Conclusions

This scoping review shows that the focus on inclusivity in education as expected has been in the context of the disabled, in other words, persons with disabilities. In the context of South Africa, inclusivity in education may be attributed to the context of two dimensions, particularly of historically disadvantaged persons who are predominantly from black areas, and persons with disabilities. The scoping review therefore presents that inclusivity in the digital and/or postdigital eras is to be reconsidered and redefined. Sequel to the findings from the analysed relevant reviewed literature and submissions adapted from the work of scholars whose works were analysed, the following recommendations are made to educational leaders in specifically:

- Distance education should be reconsidered to include issues revolving around disabilities in the context of technology. This could be as a result of learners' lack of access to needed technological gadgets and technology such as computers, internet connectivity, technological skills and so forth.
- Additionally, policies of inclusivity in education should be reviewed and revised to include technologically challenged persons.

6. Limitation and Further Suggestion of Study

The paper was limited to a scoping review using previously conducted research and published articles in the selected field in the context of South Africa. Thus, it is further suggested that similar study be conducted in this regard using a quantitative and/or qualitative or mixed method approach. Similarly, the study can be conducted in the context of some countries. Additionally, further study could be conducted with search terms which "distance education" rather than "distance" AND "education". Additionally, the outcome of the study is much broader than inclusion and technology but rather the features of inclusivity in South Africa; thus, similar study can be replicated in other countries to explore how inclusivity is treated and presented.

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Review

Successful and Emerging Cyberbullying Prevention Programs: A Narrative Review of Seventeen Interventions Applied Worldwide

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Abstract: The advent of the internet has channeled more online-related tasks into our lives and they have become a pre-requisite. One of the concerns with high internet usage is the multiplication of cyber-associated risky behaviors such as cyber aggression and/or cyberbullying. Cyberbullying is an emerging issue that needs immediate attention from many stakeholders. The aim of this study is to review existing successful and emerging interventions designed to prevent cyberbullying by engaging individuals through teacher professional development and adopting a whole-school approach. The review presents the strengths and limitations of the programs and suggestions to improve existing interventions. Preparing interventions with a strong theoretical framework, integrating the application of theories in interventions, promoting proactive and reactive strategies in combination, beginning with baseline needs assessment surveys, reducing time on digital devices and the digital divide among parents and children, promoting the concepts of lead trainer, peer trainer, and hot spots, focusing on physical activity, and use of landmarks are some of the recommendations proposed by the authors. In addition to face-to-face intervention sessions, it is suggested to update existing intervention programs with games and apps and to evaluate this combination.

Keywords: cyberbullying; anti-bullying programs; teacher professional development; individualized training; whole-school intervention

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1. Introduction

The advent of the internet has channeled more online-related tasks into our lives and they have become a pre-requisite. One of the concerns with high internet usage is the multiplication of cyber-associated risky behaviors such as cyber aggression. The term "cyberbullying" is defined as the deliberate infliction of harm using electronic methods, targeting individuals or groups of people, regardless of their age, who perceive such actions as offensive, derogatory, harmful, or unwanted [1]. Despite efforts and interventions, cyberbullying and hate messaging is still on the rise worldwide [2,3]. Many interventions deal with traditional/face-to-face/offline school bullying and are modified for cyberbullying issues on the basis of the similarities shared by both types of bullying behavior, such as unjustified aggression, being based on a power imbalance, and persevering over time [4,5]. Despite similarities, there are also differences, as stated by Smith (2012), such as cyberbullying requiring technological expertise, the unidentified perpetrator does not usually see the victim's reaction instantly, the roles of bystanders are more complex, and there are differences in intentions [6]. It is difficult to protect oneself against cyberbullying, as nasty messages or content can be sent to mobile phones, computers, or social media anytime and anywhere within seconds [7]. Berne et al. (2019) reported that experiencing cyberbullying as a victim results in negative emotions, including anger, anxiety, fear, and shame [8]. Furthermore, victims of cyberbullying tend to exhibit more somatic symptoms, such as headaches and stomachaches, than their peers who have not experienced cyberbullying. Cyber victims also tend to report lower satisfaction with their overall appearance, body image, and weight than non-cyber victims. Additionally, it was found that female victims of cyberbullying reported a more negative perception of their general appearance in comparison to male victims of cyberbullying [8]. Considering the global prevalence and detrimental consequences of cyberbullying, researchers have proposed preventive and interventional approaches to discourage children and adolescents from cyberbullying [9]. Additionally, strategies have been developed to help cyber victims manage adverse effects. These prevention methods also encompass school-based interventions, involving the training of teachers and staff members to enhance the overall school environment and foster a conducive learning atmosphere [9].

The meta-analysis conducted by Gaffney et al. (2019) indicated that cyberbullying intervention programs have proven effective in reducing both cyberbullying perpetration and victimization [10]. However, a recent systematic review by Torgal et al. (2023) demonstrated that the overall treatment effects of school-based cyberbullying intervention programs were not statistically significant [11]. These findings highlight the importance of conducting more comprehensive evaluations of cyberbullying intervention programs to identify the factors that contribute to the overall success rate of these programs.

The purpose of this study is to review and evaluate evidence-based individual training, teacher professional development programs, and whole-school anti-bullying interventions to control cyberbullying. This review examines the commonalities and distinctions among various cyberbullying intervention programs, considering factors such as the theoretical framework employed, content, activities, duration, inclusion of baseline needs assessment, allowing participants to adapt their learning, utilization of computer games and online resources as intervention tools, engagement of peers, and the incorporation of diverse incentives to motivate participants. The authors also aim to determine and compare the strengths and shortcomings of the interventions and to make recommendations for improvements. For this narrative review, the first author conducted a Google search using keywords like "school-based cyberbullying interventions", "individual training for cyber control", and "interventions through teacher professional development", etc. She specifically focused on interventions that demonstrated some level of effectiveness, ultimately identifying approximately 65 interventions that had been implemented and evaluated at the time of review. To ensure the credibility of the interventions, only those with multiple evidence-based research publications were included. After studying 17 of these interventions, the first author observed that the content and activities of subsequent interventions were largely repetitive. This led her to conclude the study at the 17th intervention.

The review classifies the interventions into three categories: engaging individuals in cyberbullying interventions, implementing teacher professional development, and adopting a comprehensive whole-school approach. The interventions aimed at curbing cyberbullying through teacher professional development were developed in response to research findings. These findings indicated that teachers held contradictory views and assumptions about cyberbullying, but through professional development, their perspectives were brought into alignment [12]. Furthermore, it was discovered that a strong bond between students and teachers can decrease the likelihood of negative bullying outcomes [13]. Another benefit of involving teachers was the cost-effectiveness of teacher-led interventions in comparison to externally delivered programs, making them a viable choice, particularly in low- to middle-income countries [14]. Additionally, the constant presence of teachers in classrooms throughout the academic year allowed students to seek help whenever needed in cases of bullying or victimization [15]. Conversely, offering direct support to individual students or victims was based on the premise that this approach eliminated the necessity for victimized children to reach out to adults. This safeguarded youngsters from harboring suspicions and facing accusations from adults, empowering them to independently confront bullying [16]. Moreover, individual interventions targeting cyberbullying spared victims from the ineffective and impractical remedies often offered by adults [17]. Comprehensive school-wide strategies were deemed more effective than individual interventions or isolated teacher professional development, largely because they involved the entire community and were perceived as highly successful [18]. To cultivate a unified community, it is imperative that parents, educators, and the community as a whole receive training on adolescent matters [19]. This training equipped them with the knowledge and skills to raise awareness and provide coping strategies, enabling them to nurture young individuals' self-esteem and establish a foundation of trust [19]. Additionally, these interventions mitigated the digital divide between parents and children [20]. Table 1 and the following sections provide detailed information about the interventions examined.

2. Interventions Designed for Professional Development of Teachers

Teacher professional development programs are based on the premise that teachers are the primary agents capable of modifying the school environment by using their competencies to reduce bullying and victimization [21]. Teacher-led intervention programs are deemed effective and cost-efficient, particularly in low- to middle-income nations, when compared to programs administered by external psychologists [14]. A review of the existing literature suggests that enhancing teacher professional development can effectively tackle behaviors that hinder or interrupt student learning, as educators require the essential abilities to handle challenging behaviors and issues related to antisocial conduct [15,22,23]. In addition, teacher-led interventions have demonstrated positive outcomes in various aspects of education, such as fostering inclusive practices, supporting children with special needs [24,25], effectively addressing challenging behaviors [23], minimizing gender discrimination, and promoting equality, among others [26]. This indicates that professional development for teachers holds immense potential not only to impact the educational environment but also to indirectly influence the community and social practices.

The literature discusses many teacher-led interventions to control cyberbullying issues, but these programs have shown contrasting results [27]. This study focused on evidence-based, successfully evaluated anti-cyberbullying programs and summarized their content, duration, similarities, strengths, limitations, and success rates. Table 1 provides an overview and the main characteristics of the programs reviewed in the present publication.

2.1. P.E.A.C.E (Preparation, Education, Action, Coping, Evaluation) Pack

P.E.A.C.E Pack is a teacher-led anti-bullying program [28] developed by Phillip T. Slee in Australian schools [29], but it has shown a significant reduction in victimization in different school settings across the globe [28,30–32]. The content of the intervention is based on social constructivism to professionally develop teachers' skills in order to teach students positive attitudes and build social-emotional skills such as kindness, sensitivity, optimism, adaptability, conflict resolution strategies, productive coping skills, and positive emotions [33]. Teachers receive a manual with step-by-step instructions on how to implement the program in classrooms [28]. General activities include teacher-led discussion sessions and group activities aimed at creating conducive relationships [28]. A video presentation with a hypothetical story of a victim is used to create empathy and serves as input for a group discussion to reflect and recognize the consequences of insults and humiliation [28]. To reinforce the concept of cyberbullying and develop a constructive self-image, optimistic attitude, and conflict resolution skills, several short videos about cyberbullying are used to reflect on the victim's feelings and how others can support the victim [28]. An investigation encompassing Australian students spanning an age range of 5.4 to 13.5 years was conducted to assess the program's efficacy in mitigating bullying [33]. The intervention was observed to be successful in decreasing the prevalence of bullying ($p < 0.01$) [33]. The program has achieved favorable outcomes in cross-cultural settings, demonstrating its adaptability to diverse cultures through a wide range of research studies [33–35], and it has the potential to be adapted for more diversified cultural settings.

2.2. ViSC (Viennese Social Competence Program)

Based on the socio-ecological model, ViSC aims to prevent school-based traditional bullying as well as cyberbullying and cybervictimization [36]. The program is implemented via several in-school teacher workshops and a class project for students [21]. Gradinger and Strohmeier (2018) elaborated the details of the intervention and explained that the program starts with training teachers to recognize and handle bullying and introduce preventative measures and interventions at the school [36].

Later, teachers are trained to disseminate the philosophy and materials of the ViSC class project to students and train them in whole-school anti-bullying culture [36]. ViSC coaches train the teachers and usually start the sessions with brainstorming discussions to analyze and connect their previous knowledge, ideas, and beliefs about the phenomenon to the current situation [36]. Hypothetical bullying case studies are used to help teachers identify bullying and develop an understanding of how to overcome or intervene in such cases [36]. Teachers are equipped with communication skills needed to empower victims, counsel bullies, and communicate with guardians in case parental involvement is required [36]. Activities such as role playing, discussions, worksheets, small group activities, interactive games, etc. are used to train children [36].

This intervention has been shown to be successful with sustainable results in different countries, and it can be applied to low- to middle-income countries. However, training ViSC coaches can add further costs to the project and a financial analysis is necessary before applying the intervention to underprivileged economies. In a study conducted in Turkey by Doğan et al. (2017), students (mean age = 10.06 years) showed significant reductions in post-victimization and perpetration ($p < 0.001$) [37]. Another study by Solomontos-Kountouri et al. (2016) in Cyprus concluded that the program was more effective for grade 7 students than grade 8 students, but no effectiveness against cyberbullying was found in grade 7 students ($p > 0.001$) [38]. Additionally, an evaluation of an ultra-short, cost-effective version of the program implemented on students (mean age 13.28 years) in Kosovo by Arënliu et al. (2020) demonstrated a significant reduction in physical victimization ($p = 0.023$), although the cyberbullying reduction was not significant [39].

2.3. Relationships to Grow (RPC)

The RPC is a short intervention based on the idea of resilience and social exclusion designed for educators to prevent cyberbullying by fostering positive relationships among students [40]. The training's content is somewhat similar to other successful and effective strategies used in other anti-bullying programs, such as Asegúrate, KiVa, ConRed, Media Heroes, etc. The aim of RPC is to disperse knowledge about cyberbullying and increase proactive coping strategies against the phenomenon [41]. The program content is based on digital literacy, raising awareness about cyberbullying and coping skills, fostering collaboration and social skills, empathy, and sensitization training [41]. The RPC is a brief intervention program conducted exclusively by teachers, consisting of 6 h of teacher training, four activities implemented by teachers in their classrooms during school hours (each activity lasting 1.5–2 h), and 1 h of teacher supervision provided by expert psychologists [41]. It is a short-term intervention for teacher professional development that can be applied to underprivileged economies to increase awareness and initiate steps against cyberbullying. The program implemented on 6th–8th grade Italian students yielded positive outcomes by enhancing students' understanding of cyberbullying and its related risk factors, as well as improving their coping skills ($p < 0.001$) [41]. However, further research is needed to confirm its effectiveness in reducing cyber victimization and perpetration [41]. These findings demonstrate the program's potential in addressing cyber risky behaviors, but further research is necessary, including more comprehensive versions of the program and detailed studies, to expand understanding of the application of this intervention.

2.4. Media Heroes

Media Heroes is based on the Theory of Planned Behavior for cyberbullying prevention [42]. Media Heroes is a psychosocial intervention that aims to create and improve empathy/awareness among youth by involving their teachers and parents [42]. The program aims to raise awareness of cyberbullying and the consequences of perpetration and victimization, as well as to teach skills for safe use of the internet and supporting positive responses from bystanders [43]. Initially, teachers are trained by psychologists with use of a training manual to implement their skills within the existing school curriculum [44]. Part of the training program is to keep educators informed about student media use/activities that support and encourage healthy discussions between teachers and students beyond the context of the intervention. The program is delivered through a variety of techniques, including peer-to-peer tutoring, watching videos, presentations, role playing, discussions, debates, etc. [45]. To raise awareness among parents, students prepare a short "workshop" in which they present their perspective and information using a variety of activities such as role play, discussion, posters, and flyers [46]. It addresses teacher professional development in the curriculum and is also available in a short version (4 sessions for 90 min), which makes it economical for low- to middle-income countries; however, a short-term program still needs to be further developed to produce more profound results in reducing cyberbullying and victimization [41]. A study was conducted by Schultze-Krumbholz et al. (2015) on 722 high school students (mean age = 13.36 years) to determine the effectiveness of Media Heroes in reducing cyberbullying [43]. While the short-term intervention did not significantly affect cyberbullying change ($p = 0.113$), the long-term intervention was effective ($p = 0.004$) [43].

2.5. Asegúrate

The Asegúrate program aims to professionally equip educators to use a full range of resources to combat cyberbullying and its consequences [47]. The activities of the Asegúrate program are based on three important psychosocial theories: the Theory of Normative Social Behavior, the principles of constructivist methodology, and the development of self-regulatory skills [48]. Activities based on the principles of constructivism reflect preexisting ideology and beliefs about the phenomenon, and sessions are developed to first understand participants' beliefs through brainstorming sessions [48]. Self-regulation skills are developed through reflection exercises to improve students' metacognitive skills and strategic learning [48,49].

Del Rey et al. (2019) provided details of the program, which is guided by a manual, audiovisual posters, stickers, and bookmarks to create awareness of cyberbullying and its consequences, the role of social networks in communication, maintaining anonymity in online activities, safe online practices, cyber gossip, sexting, cyber etiquette, and digital citizenship. Access to additional resources and information, such as reading materials, video links, etc., are also provided to teachers to further build their skills [48]. Teachers are also trained to engage students and families in training and awareness campaigns using a variety of methods [48]. The activities carried out by the teachers for the students are planned systematically, considering the students' activities and reflection on these activities and their consequences [48]. The final session ends with an individual and/or group of students making a commitment to actively address cyberbullying, which is one of the unique features of this project [47]. Researchers using a quasi-experimental approach conducted a study involving 479 secondary students (mean age = 13.83 years) that encompassed two measurements over time. The outcomes indicated that cyber aggression escalated without intervention, but decreased when the intervention was implemented ($p = 0.011$, $\eta^2 = 0.151$) [47].

3. Bullying Prevention by Training Individuals

Adolescent victims often hesitate to confide in adults about their problems. They highly value privacy and seek anonymous assistance through peer support [50,51]. There are reports suggesting that young individuals avoid involving adults in victimization matters due to a lack of trust and fear of being blamed [16]. Frequently, children choose not to disclose incidents of bullying because they feel ashamed of being a target [16]. Despite encouragement, many bullied students refrain from disclosing or seeking adult intervention in their difficulties [52] and typically reach out to their peers for assistance. Sulkowski et al. (2014) concluded that in most cases of reporting to adults (about 2 out of 3), the strategies offered were either unsuccessful/unhelpful or made the situation worse [17]. Based on this conclusion, the following interventions aim to practically empower individuals to cope with bullying. During individual training sessions, victims receive instruction on how to advocate for themselves and protect themselves against continued bullying without relying on teachers, peers, or parents. This empowers them to avoid shame and prevents labeling as victims. They do not need to disclose their personal struggles and secrets to their acquaintances, which maintains their self-identity and self-esteem. However, lack of adult supervision and loss of motivation over time lead to high dropout rates and call into question the effectiveness of such programs, which aim to train individuals to cope with bullying on their own.

3.1. Stand-Alone (Stop Bullies Online)

Stop Bullies Online/Stop Online Bullies is one of the applications in the Stand-Alone program and is designed for cyber victims (12–15 years) to empower themselves against bullying using an online, computer-tailored intervention [53]. The contents of the program were developed using multiple strategies, such as information gathered from a literature review, data collected through a Delphi study among experts, focus group interviews with the target group, and successful elements from a previously tested anti-bullying program [54]. The program is delivered through web-based counselling, with the first part changing participants' behaviors through reflection and debate, replacing irrational thoughts with impartial and balanced reasoning [53]. The second part provides awareness of cyberbullying and its consequences, bystander roles, and information on effective coping strategies to resist bullying [53]. Finally, individuals are trained to avoid risky online behaviors and safely use the internet and mobile phones [53]. The distinctive feature of the program is that content delivery is based on intervention mapping in which every component of the advice is personalized to the participants' personal characteristics (i.e., their self-efficacy, the way they cope with problems, and (ir)rational thoughts). This is considered a useful strategy for needs assessment and to find effective solutions [55]. Direct student involvement and lack of adult supervision can be ambiguous, as students tend to lose motivation or discipline and sometimes become disinterested or reluctant to be part of the program. Further research is recommended to confirm this program's effectiveness.

3.2. Cyberbullying Sensitization Program

The Cyberbullying Sensitization Program was created, executed, and assessed in an Indian region with the premise that raising awareness and sensitization about bullying would be beneficial. The program focuses on equipping individuals with the necessary skills to protect themselves from cyberbullying and promote positive online behaviors [56]. This intervention aims to raise children's awareness of cyberbullying as a coping strategy [56]. The program content creates awareness among youth and provides information about online bullying and its consequences, different types of bullying, threats, safety, and strategies to save oneself and others from unsafe risky online activities [56]. Targeted group discussions with adolescents about online bullying were the main methods used to develop this program, followed by an extensive literature review [57]. The intervention was developed by involving youth who were either perpetrators or victims of bullying and collecting their ideas, which can be considered a strength of the program [56]. The content validity of CBSP was determined by 14 experts in the fields of education, ICT, and law [56].

The intensive program consists of exercises designed to create awareness regarding the online world, activities, motivational reasons, strategies for dealing with cyberbullying, identifying bullying, the role and responsibility of bystanders, and recommendations for online safety [56]. Some of the common activities used to teach the content are role playing, case studies, video presentations, and creative writing [19]. The strategies and content are similar to most Western interventions. The qualitative study conducted on 14–15-year-old students yielded encouraging outcomes by enhancing students' awareness of cyberbullying and fostering positive online behaviors [56]. This project provides a good start for under-resourced countries to take initiative against bullying.

3.3. Informational Motivational Behavioral Skills (IMB)

Information Motivational Behavioral Skills (IMB) is founded on a strong theoretical framework and based on the health behavior change framework proposed by Fisher and Fisher (1992) [58]. The framework is based on the enrichment of cognitive skills (information and motivation) and behavior (such as improvement in practical skills) [59]. The IMB model is not only focused on providing information about cyberbullying and its consequences, but also on motivating individuals to develop positive behaviors to prevent cyberbullying and develop practical skills that can help control online risk factors [59]. The unique feature of this intervention is that it is tailored to the individual's current information, motivation, and behavioral skills. This makes it particularly relevant and effective for specific characteristics and contexts [60]. Discussions, card-making group activities, sharing experiences, reflecting on self-practices, and developing a problem-solving attitude are targeted activities in the intervention [59]. A follow-up questionnaire is also utilized to evaluate the effectiveness of the program. The components and goals of this intervention are similar to those of other interventions that focus on disseminating information, engaging in skill-building activities, recognizing bystander responsibility toward victims and perpetrators, and creating a positive classroom environment. The research findings on 13–16-year-old South African female students revealed that the intervention group exhibited a higher perception of online risks ($p = 0.001$, $\eta^2 = 0.07$) [59]. This indicated the effectiveness of the intervention in enhancing online risk perception, which is a crucial factor in promoting positive behavioral change, with a small effect size [59]. Researchers have recommended that the program's effectiveness can be improved by applying it in long-term studies.

3.4. Prev@cib Anti-Bullying Program

Prev@cib is based on three theoretical frameworks: the ecological model, Empowerment Theory, and the personal and social responsibility model [61]. The ecological model is the most studied theory used in cyberbullying interventions to combat bullying by involving not only the individual, but everyone in the environment who can contribute to the intervention [62]. Empowerment Theory focuses on the empowerment of individuals and their resources to enable youth to take control of their lives in both virtual and school settings [63]. The personal and social responsibility model, as the name indicates, encourages shared responsibility in problem-solving to achieve greater involvement of adolescents in creating a bullying-free culture [64]. Prev@cib consists of three modules that start with raising awareness regarding cyberbullying and its consequences, with a special focus on sexting and cyber grooming [61]. In the second phase of the program, sensitization, empathy towards victims, and understanding social responsibility are highlighted through different activities [61]. The Prev@cib program is essentially designed to educate students, but teachers' opinions are also sought for successful implementation [61]. The study findings by Ortega-Barón et al. (2019) on secondary students (mean age= 13.58 years) revealed noteworthy reductions in bullying, victimization, cyberbullying, and cybervictimization within the experimental group, as opposed to the control group [61]. The findings revealed that in the control group, cyberbullying exhibited a consistent level, whereas in the experimental group, it demonstrated a reduction ($p < 0.01$) with a modest effect size of $\eta^2 = 0.05$. As for cybervictimization, a minor increase was noted in the control group, whereas the experimental group experienced a decrease ($p < 0.001$) with a slight effect size of $\eta^2 = 0.04$ [61].

These results demonstrated the effectiveness of the Prev@cib program in reducing bullying and cyberbullying [61]. The program has produced successful results in Spain; however, more research-based studies are needed in the national and international context to further elaborate on the outcomes of this program.

4. The Whole-School Approach

The whole-school approach is based on the belief that bullying is a systemic problem and that interventions need to focus on the whole-school context, rather than individual bullies and victims [18,65]. Interventions based on the whole-school approach seek to effectively prevent bullying and promote safe, supportive, responsible, engaged, and thriving school communities through ongoing school climate development and reform [66]. However, there are certain limitations associated with a whole-school approach, such as high cost, time commitment, and the need for a high level of support from schools as well as full parental cooperation [67].

4.1. KiVa Anti-Bullying Program

One of the most successful school-based, teacher-led interventions aims to raise awareness of bystander responsibility in promoting bullying, increase sensitivity to victims, and help individuals use strategies to support themselves and victims against bullying [68]. These goals are achieved by engaging children and adolescents, with the help of teachers, in activities such as discussions, presentations, illustrations in the forms of pictures, figures and characters to depict different aspects of cyberbullying, short films, assignments with various learning-by-doing exercises, and a computer game in which students practice new skills against bullying in a virtual environment, with the goal of improving students' understanding and knowledge of cyberbullying [68].

When bullying incidents are reported, KiVa-trained school members engage the individuals and groups involved in bullying in conversations to counsel them and correct their behaviors [68]. KiVa also provides materials for teachers and other staff and arranges meetings with them to provide step-by-step guidance and instruction for curriculum lessons to ensure the consistency of teachers' behavior and maintain program quality [68]. Teachers have the opportunity to design their lessons using the program's manual [68]. A guide for parents is designed to provide information about the different forms of bullying and recommendations for prevention when the problem is reported. It also encourages parents to work with the school and teachers to create an effective anti-bullying culture [69]. Visible symbols, logos, imprints on teachers' vests or shirts, and posters are used to make it clear that the school is a KiVa school and bullying incidents will not be tolerated [68].

Williford et al. (2013) undertook a study involving Finnish students in grades 4 to 9, aiming to ascertain the impact of the KiVa intervention on cyberbullying. The study indicated that the influence of the KiVa intervention on post-test cyberbullying outcomes was influenced by students' age. The intervention was notably effective for students aged below 12 years ($p < 0.01$) [69]. For more studies, refer to Table 1.

4.2. Olweus Bullying Prevention Program (OBPP)

Based on the idea that bullying should not be part of a child's natural environment, OBPP is one of the most studied and successful anti-bullying efforts in the world [18,70]. The program was originally designed for school children to control violence in schools, but later evolved and expanded to control youth aggression in online settings as well [71]. Like other successful interventions, baseline information is collected to target the program and tailor the interventions for the individual as per needs assessment [72].

The OBPP begins by changing the behaviors of adults in the school to show affection and interest in students' lives, promote rules and regulations against violent behavior, and present themselves as positive role models [73]. In addition, school staff are trained and held accountable for monitoring "hot spots" in order to intervene immediately in bullying behaviors [71]. Identifying bullying incidents and counseling perpetrators, victims, and their parents through serious talks are also part of the staff training [18]. Group discussions and school staff meetings become regular practice after the implementation of OBPP to reflect on bullying and related prevention efforts at the school [18]. For children and youth training, teachers are encouraged to hold regular class meetings to express and remind goals and ground rules through activities such as role playing, small and large group activities, and discussions [18]. The meeting topics are decided by staff members and serve as an awareness program to illustrate types and subtypes of bullying and promote awareness about respecting others, coping with stress, problem-solving, and using consistent positive and negative consequences [18]. A Bullying Prevention Coordinating Committee (constituting 8 to 15 members from a school) is responsible for all staff training, organizing awareness events, improving school supervision plans, and endorsing school anti-bullying rules [18]. Family nights and after-school leadership programs for adolescents are also designed to involve the community in awareness and prevention programs [18]. The extensive longitudinal investigation conducted by Olweus et al. (2019) involved over 30,000 students in grades 3–11 across 95 schools in central and western Pennsylvania spanning a 3-year period. The study utilized a quasi-experimental extended age-cohort design to examine self-reported instances of bullying behaviors. The outcomes demonstrated that OBPP yielded favorable results in decreasing all forms of bullying, whether experiencing it or perpetrating it ($p < 0.05$) [71]. Similarly, Bowland's short-term study (2011) exhibited a statistically significant decrease in the prevalence of bullying ($p = 0.022$) and instances of peer exclusion ($p = 0.009$) among 7th grade female students. However, there was variability in the statistical outcomes for 8th grade females, and no significant findings emerged for males [74]. OBPP has been most successful in long-term studies. However, a shorter version of the program was found to be less effective (Refer to Table 1).

4.3. MARC Anti-Bullying Program

The Massachusetts Aggression Reduction Center (MARC) has developed a school-wide anti-bullying program to raise awareness and provide solutions to children's social problems, with a focus on bullying and cyberbullying, and to create an overall nurturing school environment [75]. The MARC intervention begins with basic information to customize the program and continues to evolve and improve through ongoing research [76]. The elements of the program are complementary to Olweus' interventions, developing opportunities for teachers to increase awareness, knowledge, concepts, and practical interventions to address bullying and cyberbullying [76]. In addition, MARC includes training a lead trainer in the staff training component and students who are considered authority figures and high-level peers, and these continue to train colleagues and other staff and help younger students in accordance with the program content of MARC [76]. To raise awareness among parents and the community, presentations are developed that provide practical and concrete knowledge about how to eradicate the problem and useful strategies to help adults talk to their children about the phenomenon, ask schools for help, and assist school administrators in successfully resolving bullying situations [76]. In addition, presentations and campaigns led by trained older students continue to reinforce awareness raising for younger children. Program elements for students are accompanied by guides for teachers and parents to reiterate key points and encourage classroom discussions [76]. MARC also holds annual quizzes and contests where students present posters, write poems, create public service announcements, etc. to encourage and recognize positive student behaviors [76]. In addition, MARC curricula are available free of charge to students internationally, which has led to many success stories of the MARC anti-bullying program [76]. The study by McCoy et al. (2018) involving 6th and 7th graders from a middle school in Massachusetts revealed that the qualitative program under investigation received primarily favorable feedback. The students acquired fresh knowledge and became effectively motivated. Students resonated most with the comprehensive insight they gained into digital behaviors and cyberbullying. The practical and straightforward advice presented was highlighted as one of the most beneficial components of the program [76].

However, because cultural differences may make it difficult to implement the positive elements of the program, it is recommended that extensive preparation be undertaken to implement the program in other cultures [77].

4.4. ConRed Program

The Knowing, Building, and Living Together on the Internet Program [Conocer, Construir y Convivir en la Red, ConRed] was primarily designed to cope with cyberbullying and its consequences, incorporating psycho-educational research into key intervention strategies for dealing with bullying behaviors [78,79]. Although the ConRed program is based on a holistic school-based approach, the most important target group is students who are technically trained, along with improving their communication and social skills in the online world [80]. The design of the program was based on the assumption that strategies to tackle traditional bullying can be effectively utilized in preventing cyberbullying. The program adopts the Theory of Normative Social Behavior (TNSB), which has proven successful in behavior modification [81], explaining that social behaviors are particularly inferred from peer group intimidation and are heavily influenced by perceived social conventions regarding online behaviors, which are expressed in the form of frequent uploading of personal information and images and constant connection to the virtual world [82].

The three main components of the ConRed program are working on internet addiction, bullying, and empathy [80]. ConRed intervention experts also work with each school's climate planning team for three months to improve perceived control over information available on the Internet, reduce time spent on digital devices, and prevent cyberbullying [80]. The program also involves the implementation of clear policies to combat risks associated with the internet and online social networking, with a special focus on fostering empathy [83]. The main themes of topics covered in the training session include awareness of the internet and social networks, their advantages and risks, and strategies to address online bullying [80]. The program is also based on reflection sessions with quizzes to stimulate consolidation of the acquired knowledge. Like other successful interventions, this program starts with preconceived notions of teachers, parents, and students and ends with a reflection quiz to obtain feedback [80]. Up until now, the program has yielded favorable outcomes and holds promise for application in multicultural environments [80,82]. In a secondary school setting (average age = 13.8 years), Ortega-Ruiz et al. (2012) conducted a study in Spain which disclosed that there was a notable reduction in internet addiction ($p < 0.05$) as well as cyberbullying levels ($p < 0.01$) among male participants. Both boys and girls experienced a decrease in victimization ($p < 0.05$) [80]. In a separate investigation by Del Rey et al. (2016) involving secondary school students aged between 11 and 19 years, it was determined that the ConRed program effectively lessened cyber aggression among male students ($p = 0.04$), although its effectiveness was comparatively lower for female students. In terms of cyber victimization, the experimental group exhibited a decrease, particularly noticeable among boys, while an increase was observed among boys in the control group ($p = 0.003$) [82]. These results were attributed to the intervention's feature of recognizing pre-existing notions held by teachers, parents, and students and adapting them to suit the unique requirements of each institutional setting.

4.5. TABBY Anti-Bullying Program

The Threat Assessment of Bullying Behaviors Among Youngsters (TABBY) Internet program is based on Ecological Systems Theory and is one of the interventions in which instruction is provided through online media to reduce cyberbullying and increase awareness of cyber risks [84,85]. Teachers are provided information about cyberbullying in comparison to traditional school bullying, the risks associated with cyberbullying and cybervictimization, and skills to identify, prevent, and address cyberbullying and cybervictimization [85,86]. Legal issues related to cyberbullying are also discussed in the training module for teachers [85]. The TABBY toolbox is provided as an additional resource that includes a checklist, brochure, and videos, and its use is also explained in detail [85]. Parent seminars are also organized to raise parents' awareness of the issue and provide them with strategies for intervening and preventing risky behaviors [85]. The sessions with the students are based on group brainstorming sessions in which the differences and similarities between jokes, cyberbullying, and aggression are shared and understood by the students [85]. The video sessions are used as stimuli for discussions about students' roles in the virtual world, which is expected to lead to the development of rules and strategies for safe online behaviors [85]. Eventually, the new rules and strategies are shared with the entire school and become part of the school's cyberbullying policy [85]. The outcomes of the TABBY intervention among students aged 13–14 years in Greek secondary schools indicated a decrease in risky behaviors related to cyber activities in the post-intervention results. However, there was no statistically significant difference observed in the post-intervention data between the control and experimental groups (p = 1.99) [87]. While Tabby is already a comprehensive program, incorporating a baseline survey can further enhance its effectiveness in implementing interventions within cross-cultural and social contexts. By incorporating the feature of recognizing pre-existing notions held by teachers, parents, and students, and then adapting the program accordingly to meet the specific needs of each institutional setting, it will become better equipped to address cross-cultural differences and tailor interventions accordingly. This additional step can greatly contribute to its suitability in diverse cultural settings.

4.6. Cyber Friendly Schools

Cyber Friendly Schools is based on Social Ecological Theory, and its components are developed by incorporating young people's opinions and suggestions to address technological needs and their consequences [88]. To create a positive school environment and combat a bullying culture, strategies are used that equip schools with knowledge about cyberbullying and tactics to support students' emotional and social development [89]. In addition, strategies are developed to strengthen links between schools, homes, communities, and sanctions for cyberbullying practices [89]. Further, student "cyber leaders" are recruited and trained to support staff and other students against bullying and victimization, based on the assumption that teens have a greater awareness of technology and online behaviors than adults [89]. School project teams are provided with resources, including a brochure and student activity booklet, to gather and consolidate basic information about cyberbullying, consequences, legal action, common student online activities, and bystander impact. The booklet also details strategies for school staff to deal with cyberbullying situations [89]. Finally, newsletters discuss in detail updating social media friends lists, students' digital reputation, cybersecurity, and legal issues, which is one of the unique features of this intervention [89].

Teaching and learning resources with different types of activities and online quizzes are provided to receive and provide information to increase their understanding and skills to address bullying [89]. The evaluation of the intervention applied to students aged between 13 and 15 years yielded mixed results in terms of effectiveness, as teachers implemented it poorly due to lack of time and additional time spent on regular school activities [90]. Cyber victimization decreased from years 1 to 2 (p = 0.034), but stability was maintained between years 2 and 3 (p = 0.193). Conversely, perpetration declined from years 1 to 2 and then to 3. However, the significant negative trend was only statistically significant during the period between the second and third data collection points (p = 0.006) [90].

4.7. Learning Together

Learning Together is a U.K school-based intervention aimed at improving young people's health and wellbeing, using an innovative whole-school corrective approach that aims to prevent or resolve conflicts between students and staff and prevent bullying to minimize the harm associated with such problems [91,92]. It also provides an opportunity for victims to report and share their feeling with teachers and obtain guidance. Learning

Together consists of staff training in restorative practice, convening and facilitating a school action group, and a social and emotional skills curriculum for students. Learning Together applied to secondary school students for three years had small but significant effects on bullying (control group, mean bullying = 0.34, SE = 0.02 versus experimental group, mean bullying = 0.29, SE = 0.02), which could be important for public health, but it had no effect on aggression (SE > 0.05) [89]. This is an emerging curriculum and needs evidence-based research trials to validate the outcomes. Moreover, the addition of components to handle cyberbullying issues, using baseline survey information, adopting a theory-based approach, and involving teachers and youth in developing or modifying the curriculum are also recommended.

4.8. No Trap

No trap is a web-based, online, peer-led approach based on Ecological Systems Theory [93]. The program is delivered in the form of teacher and peer group manuals that serve as resources for their training, in addition to web-based and Facebook information pages [93]. Teachers first receive basic training to raise awareness and intervene [93]. Teachers then actively participate in classroom activities conducted by peer groups and assist their peers in implementing the program with each group of students [93]. During student training, psychologists address these issues by conducting awareness sessions to promote empathy and sensitivity, the role of bystanders, and practical skills through video, discussion, and role playing [93]. Peer leaders receive in-depth training to improve their listening skills and learn how to respond to victims when approached by their peers for help [93]. The final part is equipping leaders with problem-solving and coping strategies to problems [93]. This program has been successfully tested and yielded robust results in a study wherein peer leaders (mean age = 14 years) were volunteers (victimization: $B = 0.025$; SE = 0.005; $p < 0.001$; bullying: $B = 0.017$; SE = 0.004; $p < 0.001$), but undesirable results when the peer leader was appointed by classmates (victimization: $B = -0.000$; SE = 0.006; $p = 0.958$; bullying: $B = 0.005$; SE = 0.005; $p = 0.250$) [94]. It is advisable to delve deeper into the factors contributing to the lack of success in peer interventions when students are responsible for appointing their peers. This method, which allows students to exercise autonomy and the right to vote, is widely favored and considered an effective means of selecting student representatives, aligning with democratic principles. Therefore, a thorough exploration of the reasons behind its failure would be beneficial.

Table 1. Comparison of the interventions studied.

Intervention	Country of Program Development	Country of Program Implementation	Theory/Concept	Duration	Baseline Survey-Needs Assessment	Targeted Outcome Variable	Approach *	Evaluation
Interventions Based on Teacher Professional Development								
PEACE (Preparation, Education, Action, Coping, Evaluation) Pack https://www.flinders.edu.au/research/peace-pack-phillip-slee (accessed on 22 August 2023)	Australia	Australia, Italy, Greece, Japan, Malta, Canada	Social Constructivism	6 h	No	Traditional bullying (potentially adaptable for cyberbullying)	Proactive	Promising results [28,30–32]
ViSC (Viennese Social Competence Program) http://www.viscprogram.eu/ (accessed on 22 August 2023)	Austria	Austria, Germany Kosovo, Cyprus, Romania, Turkiye	Social Ecological Theory [95]	4 modules in two semesters and several in-school workshops for teachers	Yes	Traditional bullying (potentially modifiable for cyberbullying	Proactive	Promising results [37–39], partially successful [96]
Relationships to Grow (RPC)	Italy	Italy	Resilience and Social Exclusion	6 h of teacher training	No	Cyberbullying	Proactive	Successful in creating awareness but insignificant reduction in cyberbullying rates [41]
Media Heroes	Germany	Germany, Austria, Colombia	Theory of Planned Behavior [97]	Long version: 15 sessions (at least 45 min each) Short version: 4 sessions (90 min each)	No	Cyberbullying, but has shown to be effective against traditional bullying as well	Proactive	Promising results [42,43,45,98]
Asegúrate	Spain	Spain	Theory of Normative Social Behavior, self-regulation skills, principles of constructivist methodologies	8 training sessions for teachers	No, but teachers have possibility to tailor the program according to their needs	Cyberbullying	Proactive	Promising results [47], partially successful [48]

Table 1. *Cont.*

Intervention	Country of Program Development	Country of Program Implementation	Theory/Concept	Duration	Baseline Survey-Needs Assessment	Targeted Outcome Variable	Approach *	Evaluation
Interventions Based on Individual Training								
Stand Alone	The Netherlands	The Netherlands	Not reported	3 months	Baseline information is replaced with mind mapping technique	Cyberbullying	Reactive	Promising results [54]
Cyberbullying Sensitization Program (CBSP)	India	India	Not Reported	30 h	No	Cyberbullying	Proactive	Promising results [57]
Informational Motivational Behavioral Skills (IMB)	United Kingdom-South Africa	South Africa	Health Behavior Change Framework [58]	50 min	Yes	Cyberbullying	Proactive	Successful, but with very small effect size [59]
Prev@cib Anti-bullying Program	Spain	Spain	Ecological Model, Empowerment Theory, Personal and Social Responsibility Model [64,95,99]	10 sessions (1 h each)	No	Traditional bullying and cyberbullying	Proactive	Successful in local context [61]
Interventions Based on Whole-School Approach								
KiVA Anti bullying Program https://www.kivaprogram.net/ (accessed on 22 August 2023)	Finland	Finland, United Kingdom, New Zealand, Spain, Italy, Estonia, Belgium, etc.	Social Ecological Theory [95]	2 days in school, training for teachers with follow-up sessions at university	No, but teachers can tailor the program to their needs	Traditional bullying but modified and applied for cyberbullying as well	Proactive and Reactive	Promising results [68,100–104], successful with modest effect size [69]
OLWEUS Bullying Prevention Program (OBPP) https://olweus.sites.clemson.edu/ (accessed on 22 August 2023)	Norway	USA, England, Germany	Not mentioned	A continuous training program with variations in durations for committee, staff, students, parents.	Yes	Traditional bullying but modified and applied for cyberbullying as well.	Proactive	Promising results [71,72,105], mixed results in short-term studies [74]
(Massachusetts Aggression Reduction Center) MARC Anti-Bullying Program https://www.marccenter.org/ (accessed on 22 August 2023)	USA	USA	Not Mentioned	Several components with variations in duration for staff, parents, peer leaders, lead trainers, students, etc.	Yes	Traditional bullying and cyberbullying	Proactive and Reactive	Promising results [76]

Table 1. *Cont.*

Intervention	Country of Program Development	Country of Program Implementation	Theory/Concept	Duration	Baseline Survey-Needs Assessment	Targeted Outcome Variable	Approach *	Evaluation
ConRed Cyberbullying Intervention Program	Spain	Spain	Theory of Normative Social Behavior [106]	3-month period, external experts conducted 8 training sessions with students, 2 with teachers, and 1 with families	Yes	Cyberbullying	Proactive	Promising results [80,82]
Threat Assessment of *Bullying* Behavior among Youngsters (TABBY) Improved Prevention and Intervention *Program* (TIPIP)	Italy	Italy, Greece	Ecological Systems Theory [95], Threat Assessment Approach	12 h of teacher training, followed by sessions for parents and students	No	Cyberbullying	Proactive	Mixed results [87]
Learning Together https://www.learning-together.eu/bullying-and-cyberbullying/ (accessed on 22 August 2023)	United Kingdom	United Kingdom	Not Mentioned	Not mentioned	No	Traditional bullying	Proactive and Reactive	Significant results in bullying prevention [91]
Cyber Friendly Schools https://friendlyschools.com.au/ (accessed on 22 August 2023)	Australia	Australia	Social Ecological Theory [95]	Several components with variations in duration for staff, parents, peer leaders, lead trainers, students, etc.	No	Cyberbullying	Proactive	Successful for the first year but unsustainable in later years [89,90]
No Trap	Italy	Italy	Ecological Systems Theory [95]	4 months	No	School bullying and cyberbullying	Proactive and Reactive	Promising results [107,108], mixed results [92]

* Proactive interventions aim to prevent bullying by taking preemptive actions, while reactive interventions focus on responding to reported or identified bullying cases.

5. Conclusions and Discussion

The exponential growth of social media platforms and versatile online games has opened up avenues for expressing aggression and negative emotions through cyberbullying, particularly when anonymity is preserved. In order to address these behaviors, this discussion focuses on existing effective interventions that have been extensively tested, as well as emerging interventions. Objectives, underlying theories, success rates, and to some extent, strengths, limitations, and suggestions for overcoming those limitations are examined. The ultimate aim is to provide recommendations for implementing these programs and suggest potential improvements.

5.1. Encountering Traditional Bullying and Cyberbullying

Traditional bullying programs have been developed and evaluated positively. According to Slonje et al. (2013), such programs can also address cyberbullying, including the implementation of school anti-bullying policies and engaging students in curriculum-based activities [5]. As a result of these conclusions, many bullying prevention programs have been upgraded to prevent cyberbullying [109] and work together to control emerging problems (refer to column 3, row 2, Table 2). Cyberbullying coexists with traditional bullying, and studies have shown that controlling one form of bullying can lead to other forms of bullying being committed by the perpetrator [110–112]. According to Kowalski et al. (2014), cyberbullying often occurs at the same time as traditional bullying, which implies that cyberbullying is more common in institutions where traditional bullying is more prevalent [112]. This assessment led to the conclusion that both forms of bullying should be addressed in intervention designs.

5.2. Strong Theoretical Framework

Theory is an essential part of scientific research and a quality theory is one that is testable, falsifiable, and parsimonious [113]. A meta-analysis by Tanrikulu (2018) found that few prevention efforts were specifically designed using a strong theoretical approach and most had no conceptual background, raising questions about which components work against bullying and why [9]. The current evaluation also found that some of the underlying theories of successfully implemented and evaluated programs were not well defined or explained, despite years of work to address bullying and its consequences (refer to row 10 in Table 2).

5.3. Baseline Information and Needs Assessment

Baseline assessments are important to serve as a benchmark for measuring project success or failure and establishing priority areas. Baseline information helps stakeholders decide which aspects of a project need more focus [114]. To address cross-cultural differences and practices, some programs began with baseline information to tailor and modify the interventions based on a needs assessments (refer to row 3, column 3 in Table 2). It is recommended that interventions be tailored to needs and begin with baseline information to sustainably address bullying. Similarly, it is not recommended to replicate and apply interventions in cross-cultural studies before they have been adapted to meet the needs of the specific population.

5.4. Unique Content of the Programs

The main theme of most of the interventions was to develop emotional skills, empathy, and awareness of victims, create a positive environment, and provide support with skills to counter bullying. However, some of the programs had additional components, such as working with intercultural skills (ViSC), online communication (ConRed), or sexting and cyber grooming (Prev@cib). These sensitive online behaviors are considered serious and criminal in nature and require more understanding and expanded education to protect children from online risks. When examining antisocial behavior, technology usage emerges as a significant factor that warrants consideration. Memmedova and Selahattin (2018) highlighted a link between frequent technology use and persistent anxiety issues [115], while Chung et al. (2019) found that anxiety is often accompanied by aggression and related behaviors [116]. Nevertheless, the interventions primarily focused on addressing bullying behaviors tended to prioritize personal grooming. However, only a limited number of interventions, such as the ConRed Program, specifically addressed technology use. It is advisable to thoroughly examine and explore the frequency of online activities as an additional component in addressing and managing bullying behaviors, alongside other relevant factors.

5.5. Use of Web-Based Training, Computer Games, and Online Support

Technology-based bullying awareness and prevention interventions have shown remarkable results in reducing bullying [117–119]. Similarly, the use of technological resources such as games, weblinks, and online resources used in previous interventions (refer to rows 5 and 6 in Table 2) can be adapted and adjusted in other interventions that involve face-to-face sessions or a blended approach. However, the effectiveness of these programs needs further research to support these changes.

5.6. Reactive/Proactive Approaches

Interventions designed to address bullying behaviors are categorized as proactive when actions are taken to prevent bullying behaviors from occurring [120]. Reactive interventions are those that take actions against bullying once cases are reported or identified to counter the negative consequences of victimization and help victims become psychologically stable through emotional regulation strategies and counseling of the perpetrator [121]. Various interventions operated with distinct components, with some focusing on preventive measures and others on mitigating bullying incidents. However, researchers assert that interventions should encompass elements that address both preventive measures and reactive strategies to manage bullying consequences. Therefore, it is recommended to adopt a combination of techniques that tackle pre-bullying behaviors and effectively address the repercussions of bullying incidents (refer to Table 1 and row 7 in Table 2).

5.7. Involving High-Status Peers

Victims are usually reluctant to share their suffering for a variety of reasons, including mistrust of adults and fear of being blamed [16]. They often seek anonymous help in a multitude of ways, such as using online browsers or peer support [50,51]. Unfortunately, only a limited number of interventions focused on involving students as counselors, supporters, and advocates for victims (refer to row 8, column 3 in Table 2). Involving peers and staff members with basic training can be successfully implemented as a reactive approach to victimization.

5.8. Empowering Participants

Some anti-bullying programs had unique features and components that could be adopted by other interventions to improve results. One of the unique features found in MARC, ConRed, and Cyber Friendly Schools was the use of quizzes and competitions for encouragement and reinforcement at the end of the interventions. Overall, these interventions have produced profound results [76,82,122]. These kinds of activities along with recognition encourage students, teachers, staff members, and the whole community to actively participate in interventions and create an anti-bullying environment. Similarly, the involvement of young people and teachers in the design of rules, policies, activities, and strategies and the provision of opportunities to modify the existing content according to needs will encourage them to be more active and provide satisfaction by giving them importance in decision making and achieving the goal of the intervention. Asegúrate, OBPP, KiVA, CSBP, Cyber Friendly Schools, and Prev@cib are interventions that focus on one or the other aspect of participants' involvement. Other interventions could also encourage implementers to achieve the goal of the intervention.

5.9. Use of Cyberbullying Recognition and Zero Tolerance Features

Continuous reinforcement through landmarks, as employed in KiVA, is a unique feature that reminds bullies of zero tolerance and victims of safety and empowerment. The use of "hot spots" in the OBPP program was also presented as a successful contribution to reducing bullying and victimization. Similar attempts to train teachers and parents to monitor "hot spots" in the cyber world are also suggested for controlling cyber-related risky behaviors.

Table 2. Strengths of the interventions.

Strengths	Supporting Literature	Interventions with Suggested Strengths
Working with both traditional bullying and cyberbullying Maintenance of peer relationships online and offline cannot be separated; therefore, cyberbullying cannot be solved apart from face-to-face interaction. Interventions should address both forms of bullying; otherwise, there have been studies showing that suppressing one form of bullying allows the perpetrator to engage in another form of bullying.	[112,123] [110,111]	P.E.A.C.E, ViSC, KiVa, OBPP, Prv@cib, MARC, No Trap, Stand Alone
Modified according to baseline information Baseline assessments are important to act as a benchmark for measuring project success or failure and establishing priority areas. Thus, it is recommended that interventions should be tailored according to needs.	[114]	OBPP, MARC, ViSC, Stand Alone, P.E.A.C.E, ConRed, IMB Model
Training of lead trainers There are limitations associated with long-term applications of interventions, such as cost, effort, and time. When the lead trainer is also trained, he or she can provide continuous assistance to other faculty members, resulting in sustainable program results.	[76]	MARC, OBPP
Web-based and online resource interventions Web-based interventions are also considered cost-effective, convenient, easily accessible, can maintain anonymity/privacy, have potential to tailor the program, and can address a large number of people.	[124]	No Trap, Stand Alone and TABBY, Cyber Friendly Schools
Use of computer games The use of computer games in bullying control interventions has been shown to significantly reduce cyberbullying. Thus, use of computer games is considered an effective method to reduce bullying and victimization.	[118]	KiVa
Components with both reactive and proactive approaches A proactive approach is practical to eliminate the issue, but providing psychological support to victims is another important aspect that needs more breadth in interventions. It is recommended that a mix of techniques be employed to handle pre-bullying behavior and post-bullying consequences.	[120]	ViSC, KiVa, MARC, OBPP, Learning Together, No Trap
Preparing high- status peers to help victims Victims usually seek anonymous help in many different ways, including through online browsers and peer support. A reactive approach to handling victimization can be implemented by providing peers with essential training. Positive peer interaction is among the strongest protective factor against being a bully/victim.	[50,51] [125]	MARC, Cyber Friendly Schools, No Trap, KiVa, Media Heroes
Components with hands-on activities In the context of cyber safety education, providing opportunities for students to observe and perform hands-on skills can benefit all types of learners. In order to ensure safe digital media use, practical skills should be part of the training.	[126]	ViSC, Media Heroes, RPC, Asegúrate, Stand Alone, CBSP, IMB, Prev@cib, KiVa, MARC, ConRed, No Trap
Incentives for active participation Students can be incentivized to participate in activities that might not be of interest to them at first, which allows them to continue participating.	[127]	MARC
Strong theoretical framework Cyberbullying perpetration is a phenomenon that can be explained by a wide range of social science theories and the majority of the initial work was atheoretical and descriptive in nature. Nevertheless, some interventions align with psycho-social theories that justify certain components.	[128]	P.E.A.C.E, ViSC, RPC, Media Heroes, Asegúrate, IMB, Prev@cib, KiVa, ConRed, TABBY, Cyber Friendly Schools, No Trap

6. Recommendations

Although many interventions have been designed, modified, implemented and evaluated, the fact is that technology is constantly increasing its impact in all areas, which could lead to more cyberbullying behaviors and consequences [129]. As technology evolves, there is a need to continually improve the measures in place to regulate these risky behaviors. When devising anti-bullying intervention programs, it is crucial to consider continuous improvement, updating, and contextualization of the program content as an important factor [33,130,131]

Shachar et al. (2016) reported that aggression can be countered by engaging students in physical and sports activities and by teaching self-control and emotional regulation [132]. In addition to health benefits, physical activity and sports engagement have been found to be effective methods of controlling bullying in many international investigations and interventions [133–135]. Consistent with the suggestions of Siddiqui et al. (2021), students who are more likely to engage in cyberbullying or risky victimization behaviors can be protected from further consequences by engaging them in sports or outdoor activities and reducing time on digital devices [136]. It is recommended that interventions be designed to reduce children's digital engagement and replace it with alternative physical activities to reduce anxiety and other associated risky behaviors [115,137].

The use of mobile applications and virtual reality (VR) as a countermeasure is also suggested by many researchers, but more evidence-based research is needed to determine the effects. For example, the "Shazam" app or "Unmute Daniel" are some of the technology-based interventions designed to create awareness and prevention of bullying [117]. In addition, virtual learning programs that use animated characters to teach youth how to respond to bullying have shown positive and effective results [119]. It is advisable to add these kinds of technology-oriented activities to existing and emerging interventions.

It is recommended that when evaluating the effectiveness of the program, results should not be validated through self-report, but conclusions should be drawn by involving multiple respondents [130].

7. Directions for Future Research

The literature has defined many theories used in the past for behavior management, such as Self-Determination Theory, the transtheoretical model, the Fogg behavior model (FBM), etc. Previous studies reported that Self-Determination Theory was only applied in correlational studies recently designed to address bullying [138–140], which shows that it has the potential to be used for designing different components of bullying interventions, specifically regarding counselling bullies to engage in more healthy activities and victims to stand up for themselves. Similarly, authors discussed the transtheoretical model to a limited extent in traditional bullying prevention [70] and in workplace bullying [141], but its comprehensive integration into successful interventions has not yet been evaluated. In order to address new forms of bullying, it is advisable that emerging theories be integrated into the design of interventions and the results monitored.

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Review

The Human Nature of Generative AIs and the Technological Nature of Humanity: Implications for Education

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Abstract: This paper analyzes the ways that the widespread use of generative AIs (GAIs) in education and, more broadly, in contributing to and reflecting the collective intelligence of our species, can and will change us. Methodologically, the paper applies a theoretical model and grounded argument to present a case that GAIs are different in kind from all previous technologies. The model extends Brian Arthur's insights into the nature of technologies as the orchestration of phenomena to our use by explaining the nature of humans' participation in their enactment, whether as part of the orchestration (hard technique, where our roles must be performed correctly) or as orchestrators of phenomena (soft technique, performed creatively or idiosyncratically). Education may be seen as a technological process for developing these soft and hard techniques in humans to participate in the technologies, and thus the collective intelligence, of our cultures. Unlike all earlier technologies, by embodying that collective intelligence themselves, GAIs can closely emulate and implement not only the hard technique but also the soft that, until now, was humanity's sole domain; the very things that technologies enabled us to do can now be done by the technologies themselves. Because they replace things that learners have to do in order to learn and that teachers must do in order to teach, the consequences for what, how, and even whether learning occurs are profound. The paper explores some of these consequences and concludes with theoretically informed approaches that may help us to avert some dangers while benefiting from the strengths of generative AIs. Its distinctive contributions include a novel means of understanding the distinctive differences between GAIs and all other technologies, a characterization of the nature of generative AIs as collectives (forms of collective intelligence), reasons to avoid the use of GAIs to replace teachers, and a theoretically grounded framework to guide adoption of generative AIs in education.

Keywords: AI; education; technology

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1. Introduction

The rapid growth in power and consequent use of generative AIs (GAIs) in recent years, especially since the release of ChatGPT in 2022, has raised or brought to prominence a wide range of concerns among educators, from student uses of GAIs for cheating [1] to teaching job losses and transformations [2] to fears about GAIs' effects on learners' sensemaking and socialization [3,4]. Equally, many have seen great promise in the use of such tools to support, engender, or reduce costs of learning [1,3,5,6]. However, there has been little that situates the discussion in theory, and still less that addresses both the educational and the technological underpinnings of the phenomenon. Most if not all commentators have treated GAIs as simply species of technologies that follow the same patterns and behaviours of other technologies and/or their roles in socio-technical systems, treating them as tools that we might use like any other. This paper challenges such a view. It presents a novel, theoretically grounded argument that GAIs represent an entirely new phenomenon in the history of our relationship with technologies, centering around the key observation that, for the first time, the technologies we have created are capable of something that closely resembles the soft, original, idiosyncratic, creative technique that was formerly the sole domain of human beings. We can no longer lay exclusive claim to the creative use of technologies.

This paper examines the consequences of this phenomenon as they relate to what we learn, how we learn, and, ultimately, the nature of human cognition itself. Concerns are expressed that, if we habitually and at scale offload not just the teaching and learning tasks that humans perform but the processes of sensemaking and creative application that underpin the doing of them to something that is not human, there are risks of losing much of the relational, tacit, and socializing value of education, of diluting the cultural roles played by educational systems, and of diminishing the cognitive capabilities of future generations because our descendants may not develop the soft skills that GAIs replace.

The paper presents and critically examines a number of approaches that may reduce the harm while leveraging the benefits of GAIs. It begins by briefly summarizing the theoretical basis for its arguments before moving on to its implications as they relate to generative AIs, concluding with a discussion of ways to limit their potentially harmful consequences.

2. Methodology

This paper presents a deductive and inferential grounded argument, synthesizing the literature from a number of fields, including that on complexity theory, the philosophy of technology and socio-technical systems, neuroscience, educational theory, and machine learning, to present the case for a new and productive way of understanding GAIs and their roles in learning. It is not a systematic review. It applies a theory of technology drawn from the author's book, *How Education Works: Teaching, Technology, and Technique* [7], that extends Brian Arthur's understanding of technologies as assemblies of orchestrations of phenomena to our use [8] to focus on the roles we play in their enactment, individually and collectively. It provides not only a means to describe the educational process but an explanation of its nature and its products in technological terms. The theory is situated in a broadly complexivist [9] tradition of educational research, related to Fawns's view of education and technology as entangled systems [10], connectivist models of learning [11,12], and distributed cognition [13], amongst others. Given that among the central premises of such theories it is stated that learning is highly situated, complex, and unpredictable at a detailed level, and that the ways technologies may develop are inherently unprestatable [14], it is a limitation of the argument that any specific predictions it makes, beyond those in the immediate future, may and most likely will be wrong. Although some possible future consequences will be presented, the intent of the argument is thus not to predict the future but to provide a way of understanding that future as it unfolds.

3. Theoretical Model

This section is a summary of the relevant aspects of the theory presented in *How Education Works* [7]. Any unreferenced claims in this section should be assumed to derive from the book itself.

We are a part of our technologies and they are a part of us. They are not just tools we use but intrinsic parts of our cognition and ways of being [15]. Equally, we are not just users of them but parts of their assembly, inasmuch as the techniques that we use when operating them are as much technologies as computers and books. Whether we are sole orchestrators (for instance, in the use of language, singing, or mental arithmetic) or parts of a broader orchestration (for instance, the ways in which we operate power stations, enact regulations, or simply turn on a light), we are, through technique, active participants in their orchestration. Sometimes, for instance, when spelling a word or telling the time, we are mechanical parts of their orchestration who must play our roles correctly. I describe these fixed techniques as *hard*, in the sense of being, when enacted correctly, inflexible and invariant. Sometimes, such as when writing a sentence or designing software, we are the orchestrators, using an idiosyncratic technique to create new technologies such as academic papers, stories, and apps. I describe such techniques as *soft*, in the sense of being flexible and variable. Most of the time, we are both orchestrators and the orchestrated, using a mix of hard and soft technique, because almost all technologies are assemblies of other technologies [8], some of which invite our own orchestration, and some of which demand that we participate correctly in theirs. For example, to play a musical instrument we must train ourselves to place our fingers, breathe, shape our lips, and tune the instrument correctly, but the things we usually value most highly are the idiosyncratic ways we play the notes.

Each new technology (including soft technique) creates adjacent possible empty niches into which further technologies may step, and relies on those created by its predecessors [16]. New technologies are not just derived from but must fit in with others that already exist; we virtually never see the wholesale replacement of one type of technology with another, in part because most technologies use services of others (cars need roads, pens need paper, etc.) and/or are made from them [8], and in part because of the natural dynamics of pace layering [17]: that in all systems, be they natural or artificial, the larger and slower moving tend to influence the smaller and faster moving more than vice versa [18]. While some small things, en masse, may be highly disruptive (viruses, say, or locusts), this is because the small parts are members of a larger collective that can be treated at a system level as a single entity. Pace layering is a facet of a larger family of path dependencies, where what has occurred in the past both enables and constrains what may occur in the future. The large and slow-moving nearly always exist prior to any individual smaller or faster phenomenon precisely because they are slower to change; they provide the background to which smaller, faster changing parts must develop and adapt. This may in turn be reframed in technological terms: technologies that are harder and more invariant, by definition, change more slowy than softer, more flexible, and malleable technologies, which must fit in and around their constraints. Thus, the harder a technology, the more embedded in relation to others it may be, and the greater its influence in a technological system.

None of us could be smart alone and no one learns alone. It is almost entirely through our technologies, from language to doorknobs, that we are able to participate in one another's cognition and, ultimately, in the ever expanding intertwingled collective intelligence of our species. We stand not only on the shoulders of giants but on those of all who came before, and of all the people we have directly or indirectly (through their creations) encountered. As we participate in our cultures, being a part of, creating, building, adapting, and assembling technologies, we all contribute to the learning of others—for better or worse—and so we and our technologies co-evolve in an endless iterative and recursive cycle leading (globally, though not always locally) to greater complexity, greater diversity, and greater technological capability [19]. We and our cognition exist for and by means of our societies that exist for and by means of us, mediated through the technologies we create and enact.

Although such learning is embedded and is simply inevitable as a result of living with other people, thanks to the complexity and diverse needs of modern societies we often need to formalize the learning of techniques (soft and hard) through a set of technological processes we normally describe as *education*. Education is not just a set of pedagogical techniques performed by those we label as teachers, but by all the participants involved: by authors of textbooks, designers of classrooms, creators of test banks, manufacturers of whiteboards, members of academic boards, creators of regulations, other students, and, above all, by learners themselves. Institutions, including their processes, regulations, structures, and infrastructures, as well as the many kinds of interactions between the people in them, teach at least as much as those who are formally designated as teachers.

Education plays a role in the development of values and attitudes that go far beyond the technological but, at its heart, and fundamental to supporting these other roles, it is concerned with building the cognitive gadgets [20] needed to participate in the many technologies of our societies. This includes training for hard skills (spelling, performing lab experiments correctly, following citation standards, using rules of logic in causal reasoning, etc.) as well as the development of soft skills (composition, problem solving, rhetoric, research design, musical expression, etc.). In other words, the process of education is largely concerned with creating, fostering, and developing technique, including technologically mediated knowledge. Every subject includes hard and soft elements of technique in varying measures: harder subjects, as the name implies, tend to focus more on hard technique, and softer subjects focus more on soft technique. Through education we learn the technologies of our many overlapping cultures, from methods of scientific experimentation to rituals of religion or the mechanics of political systems. Often, we need to develop literacies, which may be thought of as the prerequisite cognitive gadgets that we need in order to participate in other technologies of our cultures. Education itself is fundamentally technological in character, involving the assembly of methods, principles, processes, physical tools, cognitive tools, buildings, networks, and countless other technologies to enact a process in which there are countless co-participants. No one ever teaches alone, and no one ever learns alone. From obvious teachers like the authors of textbooks or directors of videos to significant players like architects or furniture designers, and above all the learners themselves, at least thousands of people participate directly or indirectly in any formal teaching process.

Technologies help us to solve problems or to create opportunities, but we are the solvers and the opportunity takers. As the technologies of our societies evolve, so too do the needs for the skills to use them and thus, so too do they become incorporated into what is taught in our institutions, in an endless cycle of renewal. Until very recently, though they nearly always support and enable the development of soft technique, the physical and virtual technologies we have created have only ever been hard, leaving the softer ways of assembling, using, and creating them to humans. Indeed, we could barely call them technologies at all were it not that there was something consistent and invariant about them. It is only our own orchestration of them that could, till now, rightly be described as soft. The development of generative artificial intelligence has changed that.

4. The Distinctive Nature of Generative AIs

GAIs, notably but not exclusively in the form of large language models (LLMs), have now developed to a point that their output closely resembles and often exceeds what humans could do unaided, performing tasks that appear to be the result of soft cognitive processes much like our own. In fact, this is because that is, to a large extent, almost exactly what they are. The "intelligence" of LLMs is almost entirely composed of the reified soft creations of the (sometimes) hundreds of millions of humans whose data made up their training sets albeit that it is averaged out, mashed up, and remixed. LLMs are essentially a technological means of mining and connecting the collective intelligence [21] of our species.

For more than a decade, conversational agents have been available that, within a constrained context, have regularly fooled students that they are human, albeit making sometimes embarrassing or harmful mistakes due to their hitherto relatively limited training sets [22] and seldom fooling the students for very long. The main thing that has changed within the past few years is not so much due to the underlying algorithms or machinery, though there have been substantial advances (such as transformers and GPU improvements), but to the exponentially increasing size of the language models. The larger the training set, the greater the number of layers and vectors, and the larger the number of parameters, the more probable that the model will not only be able to answer questions but do so accurately and in a human-like way. Their parameters (directly related to the number of vectors and layers) provide an approximate measure of this. Open AI's GPT-3, released in 2022, has around 175 billion parameters, while Google's slightly earlier BERT has "only" 340 million. However, both are dwarfed by GPT-4, released in 2023, which is estimated to use closer to 100 trillion parameters, being trained on a data set representing a non-trivial proportion of all recorded human knowledge [23]. It is because of this that modern LLMs appear to be capable of mimicking and, in many cases, that the quality of their outputs exceed all but the highest achievements in human cognition including inference [24] and creativity [25,26].

Some (e.g., [27,28]) have even tried to make the case that a GAI such as ChatGPT-4 is now at least close to being an AGI (artificial general intelligence), using measures of human intelligence and creativity as evidence. I disagree, for reasons that will matter in the discussion that follows. These measures were chosen by researchers to determine the extent to which a *human* is intelligent or creative; they rely on indicators that usually correlate with what we normally recognize as intelligent, creative behaviour in a human being. In so doing they assume, as a baseline, that the agents they are testing *are* both creative and intelligent, so the tests are a means to compare one human with another on a scale, and are not absolute standards and certainly not a proxy for the cognitive skills themselves.

To measure something requires there to be attributes that we can define precisely enough to measure. Unfortunately, both intelligence and creativity are extremely fuzzy culturally embedded concepts with meanings that shift according to context and that drift over time [29]. We know them when we see them but, if called upon to define them, we invariably come up with definitions that are too narrow or too broad, and that admit exceptions or that include things we would not see as anything similar to our own. This is inevitable because intelligence and creativity are identified by family resemblances [30], not a fixed set of defining characteristics. We see in others signals of aspects we see in ourselves, recognizing shared physical and behavioural characteristics, and then extrapolate from these observations that they emerge from the same kind of entity. The signals are, however, not the signified. The meanings we give to "intelligence" or "creativity" are social constructions representing dynamic and contextually shifting values, not fixed natural phenomenon like the boiling point of water or gravity. In them we find reflections of our own ever-evolving and socially constructed identities, not laws of nature. While we can make general inferences from correlational data, they cannot reliably predict behaviour in any single instance [31]. Tests of intelligence or creativity are broadly predictive of what we recognize as intelligent or creative behaviour, but they are highly susceptible to wide fluctuations at different times that depend on many factors such as motivation, emotion, and situation [32].

Just because the output of an LLM closely resembles that of a human does not mean it results from the same underlying mechanisms. For instance, some of an LLM's apparent creative ability is inherent in the algorithms and data sets it uses; LLMs have vastly greater amounts of reified knowledge to draw from than any individual human, and the fact that they can operate at all depends on their capacity to connect and freely associate information from virtually any digital source, including examples of creativity. If this is how we choose to define creativity then, of course, they can be very creative. It is, though, inappropriate to directly compare the intelligence, wisdom, or creativity of AIs and humans, at least in their current forms, because, even if some of the underlying neural nets are analogous to our own, they are not like us, in ways that matter when they are a part of the fabric of our own cognitive, social, and emotional development.

Unlike humans, the current generation of LLMs have not learned about the world through interactions with it, as independent and purposeful agents interacting with other independent and purposeful agents. Their pasts are invented for them, by us, and their purposes are our purposes, not their own. Although we might metaphorically describe their behaviours as goal-seeking, this is because that is how they are programmed, not because they possess goals themselves. LLMs have no intentions, nothing resembling consciousness, no agency, and no life history. They have no meaningful relationships with us, with one another, or with the tokens they unknowingly assemble into vectors. Though there may be much sophistication in the algorithms surrounding them, and impenetrable complexity in the neural networks that drive them, at their heart they just churn out whatever token (a word, a phrase, musical notes, etc.) is most likely to occur next (or, in some systems, whatever comes previously, or both), given the prompt they are given.

Perhaps something similar is true of human beings; we certainly make decisions before we are conscious of having done so and many if not all of our intentions are pre-conscious [33]. Also, like us, LLMs are prediction machines [34] and they do appear to make such predictions in a similar manner. However, as Clark [35] argues, it is not possible to jump from this to a full explanation of human thought and reason, let alone intentional behaviour. Even if there are closer similarities with our own minds, the stuff that such minds deal with is fundamentally different. Most significantly and unsurprisingly, because all it has learned has been the processed signals humans (mostly intentionally) leave in the digital world, an LLM is nothing *but* signals, with nothing that is signified underneath. The symbols have no meaning, and there is no self to which they could relate. Current systems have no concept of whether the words or media they churn out make sense in the context of the world, only whether they are likely to occur in the context of one another. If part of their output is a hallucination, then all of it is. The machines have no knowledge, no concepts, and no sense of how anything works in the context of a self because there is no identity, no purposive agent, and no being in the world to which the concept could relate. This may change as embodied AIs become more common and sophisticated but, even then, unless perhaps they are brought up like humans in a human society (a possibility fraught with huge ethical and practical concerns), they will be utterly unlike us.

Some might argue that none of this is important. If it walks like a duck, squawks like a duck, and flies like a duck then, to all intents and purposes, we might as well call it a duck. This is, again, to mistake the signal for the signified. While the output of an LLM may fool us into thinking that it is the work of an actual human, the creative choices we most value are expressions of our identity, our purposes, our passions, and our relationships to other people. They are things that have meaning in a social context, and are things that are situated in our lives and the lives of others. It matters so much, for example, that a piece of work was physically written by Gustav Mahler that someone was willing to pay over USD 5m for the handwritten score of his Second Symphony. We even care about everyday objects that were handled by particular humans; an inexpensive mass-produced guitar used by John Lennon in some of his early songwriting, for instance, can sell for roughly USD 2.4m more than one that was not. From a much loved piece of hand-me-down furniture to the preservation of authorship on freely shared Creative Commons papers, our technologies' value lies as much as or more than in their relationship to us, and how they mediate relationships between us, as in their more obvious utilitarian functions. More prosaically, we are normally unwilling to accept coursework written by an AI when it is presented as that of a student, even though it may be excellent, because the whole point is that it should have contributed to and display the results of a human learning process. This is generalizable to all technologies; their form is only meaningful in relationship to other things, and when humans participate in the intertwingled web that connects them. It is not just our ability to generate many ideas but our ability to select ones that matter, to make use of them in a social context, to express something personal, and to share something of ourselves that forms an inextricable part of their value. The functional roles of our technologies, from painting techniques to nuts and bolts to public transit systems, are not ends in themselves; they are meant to support us in our personal and social lives.

Despite appearances, we are thus little closer to an AGI now than we were 10 years ago. In fact, as Goertzel [36] observed back then, we still struggle to define what "intelligence" even means. The illusion of human-like intelligence, though, being driven by the reified collective knowledge of so many humans and, for most large models, being trained and fine-tuned by tens or hundreds of thousands more, is uncanny. To a greater extent than any previous technology, LLMs black-box the orchestration of words, images, audio, or moving images, resulting in something remarkably similar to the soft technique that was hitherto unique to humans and perhaps a few other species. Using nothing but those media and none of the thinking, passion, or personal history that went into making them, they can thus play many soft, creative, problem-solving, generative roles that were formerly the sole domain of people and, in many cases, substitute effectively for them. More than just tools, we may see them as partners, or as tireless and extremely knowledgeable (if somewhat unreliable) coworkers who do so for far less than the minimum wage. Nowhere is this more true, and nowhere is it more a matter of concern, than in the field of education.

5. GAIs and Education

The broader field of AI has a long history of use in education for good reason. Education is a highly resource-intensive activity demanding much of its teachers. We have long known that personal tuition offers a two-sigma advantage when compared with traditional classroom methods [37] but, for most societies, it is economically and practically impossible to provide anything close to that for most students. There is therefore great appeal to automating some or all of the process, either to provide such tuition or to free up the time of human teachers to more easily do so. The use of automated teaching machines stretches back at least 70 years [38,39], though it would be difficult to claim that such devices had more than the most rudimentary intelligence. AIs now support many arduous teaching roles. For instance, since at least as long ago as the 1990s, auto-marking systems using statistical approaches to identify similarity to model texts [40], or latent semantic analysis with examples trained using human-graded student work [41], have been able to grade free-text essays and assignments at least as reliably and consistently as expert teachers. For at least 20 years, some have even been able to provide formative feedback, albeit normally of a potted variety selected from a set of options [42]. Use of intelligent tutoring systems that adapt to learner needs and that can play some (though never all) roles of teachers, such as selecting text, prompting thought or discussion, or correcting errors, goes back even farther, including uses of expert systems [43], adaptive hypermedia that varies content or presentation or both according to rules adapted to user models [44], as well as rule-based conversational agents (that might now be described as bots) mimicking some aspects of human intelligence from as far back as the 1960s, such as Coursewriter [45], ELIZA [46], or ALICE [47,48]. Discriminative AIs performing human-like roles of classification have seen widespread use in, for example, analyzing sentiment in a classroom [49], identifying engagement in online learning [50], and identifying social presence in online classes [51]. From the algorithms of search engines such as Google or Bing to grammar-checking, autocorrect, speech-to-text, and translation tools, the use of AIs of one form or another for performance support and task completion has been widespread for at least 25 years, and nowhere more than in education.

For all of the sometimes mixed benefits AIs have brought, and for all of the ways they have benefited students and teachers, until now they have been tools and resources that are parts of our own orchestrations, not orchestrators in their own right. They had neither the breadth of knowledge nor the range of insight needed to respond to novel situations, to act creatively, or to fool anyone for long that they are human. Now that this is possible, it has opened up countless new adjacent possibilities. There has been an explosion of uses and proposed uses of GAIs in education, both by students and by teachers, performing all these past roles and more [5,52]. For teachers, GAIs can augment and replace their roles as Socratic tutors, providers of meaningful feedback, participants in discussions, and curriculum guides [53,54]. For students they can write assignments, perform research, summarize documents, and correct improper use of language [55]. These examples merely scratch the surface of current uses.

The effects of GAIs on our educational systems have already been profound. At the time of writing, less than a year after the meteorically successful launch of ChatGPT, recent surveys suggest that between 30% (https://www.intelligent.com/nearly-1-in-3-college-students-have-used-chatgpt-on-written-assignments/ accessed on 25 November 2023) and 90% (https://universitybusiness.com/chatgpt-survey-says-students-love-it-educators-not-fans/ accessed on 25 November 2023) of students are using it or its close cousins to assist with or often write their assessed work. Teachers, though mostly slower to jump on the bandwagon, are using these tools for everything from the development of learning outcomes and lesson plans to intelligent tutors who interact with their students, and they are scrambling to devise ways of integrating GAIs with curricula and the course process [52]. Already, in some cases it may therefore be the case that the bulk of both the students' and the teachers' work is done by a GAI. This has a number of significant implications.

Teachers, be they human or AI, are not only teaching the pattern of the cloth; they are teaching how to be the loom that makes it or, as Paul [56] puts it, the mill as well as the grist of thought. Although the language of education is typically framed in terms of learning objectives (what teachers wish to teach) and learning outcomes (what it is hoped that students will learn), there is always far more learning that occurs than this; at the very least, whether positive or negative, students learn attitudes and values, approaches to problem solving, ways of thinking, ways of relating to others in this context, motivation, and ways of understanding. It is telling, for instance, that perceived boredom in a teacher results in greater actual boredom in students [57]. Similarly, approaches to teaching and structural features of educational systems that disempower learners create attitudes of acquiescence and detract from their intrinsic motivation to learn [58–60]. Equally, the enthusiasm of a teacher plays an important role in improving both measured learning outcomes and attitudes of students towards a subject [61,62]. Such attitudinal effects only scratch the surface of the many different kinds of learning, ways of connecting ideas, and ways of being that accompany any intentional learning that involves other people, whether they are designated teachers, authors of texts, or designers of campuses. Often, teachers intentionally teach things that they did not set out to teach [63]. There are aspects of social and conceptual relationships and values that matter [59], idiosyncratic ways of organizing and classifying information, ethical values expressed in actions, and much, much more [64]. There is a hidden curriculum underlying all educational systems [65] that, in part, those educational systems themselves set out to teach, that in part is learned from observation and mimicry, and that in part comes from interacting with other students and all of the many teachers, from classroom designers to textbook authors, who contribute to the process, as well as all the many emergent phenomena arising from ways that they interact and entwine. Beyond that, there is also a tacit curriculum [66] that is not just hidden but that cannot directly be expressed, codified, or measured, which emerges only through interaction and engagement with tasks and other people.

The tacit, implicit, and hidden curricula are not just side-effects of education but are a part of its central purpose. Educational systems prepare students to participate in the technologies of their various cultures in ways that are personally and socially valuable; they are there to support the personal and social growth of learners, and they teach us how to work and play with other humans. They are, ultimately, intended to create rich, happy, safe, caring, productive societies. If the means of doing so are delegated to simulated humans with no identity, no history, no intention, no personal relationship, and with literally no skin in the game, where a different persona can be conjured up through a single prompt and discarded as easily, and where the input is an averaged amalgam of the explicit written words (or other media) of billions of humans, then students are being taught ways of being human by machines that, though resembling humans, are emphatically *not* human. While there are many possible benefits to the use of AIs to support some of the process, especially in the development of hard technique, the long-term consequences of doing so raise some concerns.

The End and the Ends of Education

We are at the dawn of an AI revolution to which we bring what and how we have learned in the past, and so—like all successful new technologies—we see great promise in the parts of us and the parts of our systems they can replace. All technologies are, however, Faustian bargains [67] that cause as well as solve problems, and the dynamics of technological evolution mean that some of those problems only emerge at scale when technologies are in widespread use. Think, for example, of the large-scale effects of the widespread use of automobiles on the environment, health, safety, and well-being.

Generative AIs do not replace entire educational systems; they fit into those that already exist, replacing or augmenting some parts but leaving others—usually the harder, larger-scale, slower-changing parts, such as systems of accreditation, embedded power imbalances, well-established curricula, and so on—fully intact, at least for now. They are able to do so because they are extremely soft; that is, perhaps, their defining feature. Among the softest and most flexible of all technologies in educational systems are pedagogies (methods of teaching). Though pedagogies are the most critical and defining technologies in any assembly intended to teach, they never come first because they must fit in with harder technologies around them; in an institutional context, this includes regulations, timetables, classrooms or learning management systems, the needs of professional bodies, assessment requirements, and so on [7]. Now that we have machines that can play those soft roles of enacting pedagogies, they must do so in the context of what exists. Inevitably, therefore, they start by fitting into those existing structures rather than replacing them. This is, for example, proving to be problematic for teachers who have not adapted their slower changing assessment processes to allow for the large-scale use of LLMs in writing assignments, although such approaches have long been susceptible to contract cheating, including uses of sites such as CourseHero to farm out the work at a very low cost. It is telling that a large majority of their uses in teaching are also meant to replace soft teaching roles, such as developing course outlines, acting as personal tutors, or writing learning outcomes. The fact that they can do so better than an average teacher (though not yet as well as the best) makes it very alluring to use them, if only as a starting point. The fact that they are able to do this so well, however, speaks to the structural uniformity of so many institutional courses. The softness that GAIs emulate means that it is not quite a cookie-cutter approach, but the results harden and reinforce norms. This is happening at a global scale.

Right now, for all of the widely expressed concerns about the student use of AIs, it is easy to see the benefits of using them to support the learning process, and to integrate them fully into learning activities and outcomes. Indeed, it is essential that we do so, because they are not just reflections of our collective intelligence but, from now on, integral parts of it. They are not just aides to cognition but contributors to it, so they must be part of our learning and its context. There are also solid arguments to be made that they provide educational opportunities to those who would otherwise have none, that they broaden the range of what may be taught in a single institution, that they help with the mundane aspects of being part of a machine so that teachers can focus on the softer relational human side of the process, that they can offer personal tuition at a scale that would otherwise be impossible, and that they therefore augment rather than replace human roles in a system. All of this is true today.

Here at the cusp of the AI revolution, we have grown up with and learned to operate those technologies that LLMs are now replacing, and our skills that they replace remain intact. This situation will change if we let it. In the first place, the more soft roles that the machines take on, the less chance we will have to practice them ourselves, or even to learn them in the first place. It is important to emphasize that these are not skills like being able to sharpen a quill or to operate a slide rule, where humans are enacting hard technologies as part of another orchestration. These are the skills for which we develop such hard techniques: the creative, the situated, and the idiosyncratic techniques through which we perform the orchestration, and that are central to our identities as social beings.

Secondly, simple economics means that, if we carry on using them without making substantial changes to the rest of the educational machine, AIs will almost always be cheaper, faster, more responsive, and (notwithstanding their current tendency to confidently make things up) more reliable. In an endemically resource-hungry system, they will be used more and more and, as long as all we choose to focus on are the explicit learning outcomes, they will most likely do so more effectively than real humans. Discriminative AIs will measure such outcomes with greater speed and consistency than any human could achieve; they already can, in many fields of study.

To make things worse, current LLMs are largely trained on human-created content. As the sources increasingly come from prior LLMs, this will change. At best, the output will become more standardized and more average. At worst, the effect will be like that of photocopies of photocopies, each copy becoming less like the original. Fine-tuning by humans will limit this, at first, but those humans will themselves increasingly be products of an educational system more or less mediated by AIs. Already, there are serious concerns that the hidden guidelines and policies (which are themselves technologies) of the large organizations that train LLMs impose tacit cultural assumptions and biases that may not reflect those of consumers of their products [6], and that may challenge or systematically suppress beliefs that are fundamental to the identities of large numbers of people [68]. The fact that the ways this happen are inscrutable makes this all the more disturbing, especially when ownership of the systems lies in the hands of (say) partisan governments or corporations. There is much to be said for open LLMs as an antidote to such pernicious consequences.

The changes to our individual and collective cognition that result from this happening at scale will be a hard-to-predict mix of positives and negatives; the average capability to do stuff, for instance, will likely improve, though perhaps the peaks will be lower and maybe valuable skills like political reasoning may be lost [5]. It is fairly certain, however, that such changes will occur. Unless we act now to re-evaluate what we want from our education systems, and how much of our soft cognition we wish to offload onto machines, it may be too late because our collective ability to understand may be diminished and/or delegated to smarter machines with non-human goals.

6. Discussion: Reducing the Risks of GAIs in Education

There is a wave of change being wrought by the widespread availability and the increasing ubiquity of GAIs, and it makes little sense to stand still as it breaks. We might channel it in useful directions if we had the time but, for now, the large and slow-moving structural changes that this would entail make it difficult, especially while the wave is breaking. This final section presents a few theoretically informed ways that we might surf the wave, taking advantage of the benefits without diverting it or standing in its way.

6.1. Partners, Not Tools

The central concern expressed in this paper is that, because GAIs are capable of closely mimicking soft technique, there are great dangers that they will replace not only the mechanical aspects of cognition but the softer cognitive skills required to use them in both teachers and learners. While, from a task completion perspective, it makes a great deal of sense to delegate tasks we cannot do well ourselves, in a learning context this may strongly discourage learners from ever learning them. Whether this is harmful or not depends on the context. For instance, as someone who has spent countless hours for over six decades trying to develop hard skills of drawing, including with the help of digital drawing tools, the author is resigned to the fact that he will probably never learn to do so sufficiently well or quickly enough for it to be a practical option for him beyond personal sensemaking or quick and dirty communication of ideas with others. It therefore seems reasonable for him to delegate illustrations of (say) slide shows or book figures to a GAI. However, it is a very different matter for a child who may never have attempted to learn such skills in the first place. While there are, at least for now, many skills needed to choose and make effective use of GAI image generation tools, so it is not an uncreative act, there are many ways in which drawing with a physical stylus or pen positively affects cognition that will be lost or diminished if this becomes the primary means of doing so. It is important to emphasize that this is not the same as, say, replacing the ability to draw straight lines with a ruler with a drawing program; the skills in jeopardy are the soft, creative, generative, intangible, constructive skills that are a part of, a creator of, and an expression of our cognition itself. This is not a repetition of the error Socrates relates when, in Plato's Phaedrus [69], he says of writing, "this discovery of yours will create forgetfulness in the learners' souls, because they will not use their memories; they will trust to the external written characters and not remember of themselves." The reality is, of course, that writing provides a scaffold, not a replacement for memory: it is a cognitive prosthesis, not an alternative to cognition. However, because GAIs actually do replace the soft skills, it is no longer so clear-cut. Later in the same passage (ibid. p. 88) Socrates goes on to say, "writing is unfortunately like painting; for the creations of the painter have the attitude of life, and yet if you ask them a question they preserve a solemn silence." A GAI may not remain so silent.

There is, though, a case to be made for the use of AIs in *supporting* a process of drawing (or writing, or making videos, and so on). Tools such as Stable Doodle, Fotor's AI Sketch, or Picsart's SketchAI can take a sketch and turn it into any number of different genres of art or image style, for instance, adding hard skills that the human creator may not have or may not have time to use. The roles they play are not dissimilar to those of the skilled technical teams supporting architects such as Frank Gehry, whose buildings benefit greatly from computer-assisted (and sometimes computer-generated) designs despite his own inability to operate a computer. He relies upon his sketches and rich dialogues with his team to turn his ideas into workable designs for buildings. The important and generalizable point is that there remains scope for soft, creative technique in the process. Similar tools, such as Grammarly or WordTune, that can perform copy-editing roles on human-written text, can be particularly valuable for those writing in a second language, and may help to scaffold the learning of such skills in the first place, without diminishing the creative, generative, soft technique of the writer. This division of roles suggests fruitful ways that we may gain the benefits of AI without losing the essential human engagement and value of the process. As a general principle it is thus better to treat GAIs as partners rather than tools, or as team members or contract workers rather than devices. This makes it easier to divide the cognitive tasks, maintaining human connection where human connection matters. This applies as much to teachers using AIs to support the development and running of a course as it does to the students' studies—in effect, it is now possible for all work to be teamwork. Ideally, more than one GAI should be a team member to reduce the effects of systematic biases and assumptions any one might hold.

What this implies for humans who, in principle, might have performed those roles in the past remains a matter for concern. For a teacher who would otherwise not have a hope of ever being able to assemble or employ the services of a professional design team, and thus the choice lies between receiving an AI's assistance or doing what they can alone, the case for employing an AI is very compelling. At scale, though, this may not bode well for professionals who do currently play those roles and, without them, there will be nothing new to feed the training of the next generation of AI. We can only hope that future generations will still value—and perhaps increasingly value—the work of verifiable humans, for all the reasons previously discussed, though the inequalities and "analogue divide" that may ensue would make this a double-edged sword.

6.2. Designing for Intrinsic Motivation

Our educational institutions have evolved to be structurally antagonistic to intrinsic motivation due to the deeply entangled path dependencies embedded in their origins, which has resulted in the phenomenon that many of our most cherished pedagogies and processes are counter-technologies that aim to restore or replace what is lost [7]. The reasons for this are essentially technological, and driven by dynamics of technological evolution described earlier. For our ancestors wishing to share the knowledge of the few with the many, prior to the widespread availability of books and the skills to read them, lectures were the only practical technology. The structural technologies of education systems were therefore primarily developed to make lectures as effective as possible. Timetables, terms, semesters, courses, classrooms that placed lecturers at the front, rules of behaviour for those classrooms, and a host of other technical solutions to this problem therefore became the basis on which all further development occurred, to the extent that they soon became among the hardest and thus the most structurally determinant technologies in the system. Out of necessity, such technologies reduce autonomy for the learners, who must acquiesce to a time, place, pace, and subject matter of someone else's choosing, doing so in an environment where control of almost every second lies with a figure of authority. Unfortunately, autonomy is what self-determination theory shows to be one of the three essential foundations for intrinsic motivation, without which it cannot occur at all [70]. Furthermore, the need for learning to occur in lock step with other students in a class means that, without much pedagogical ingenuity and skill on the part of the lecturer, some will be bored and others confused, undermining the second pillar of intrinsic motivation, the need for competence/achievable challenge. Only the third foundation, relatedness, is potentially well supported, if only thanks to the presence of other learners in the same situation. As a result, many of our most cherished pedagogies, from problem- or inquiry-based learning to direct instruction and the chunking of content, are focused on ways of restoring autonomy and supporting individuals' development of competence. This demands a lot of work, hard skill, and soft talent from a sensitive and hard-working teacher or (at greater cost) teachers, albeit that the work is assisted by campus designs that make social interaction almost unavoidable.

A more reliable, superficially cheaper, and less demanding way of ensuring students do the necessary work to learn from designated teachers is through the use of extrinsic motivation such as grades, the promise of credentials, rules of attendance, and so on, and these forms of coercion have therefore also become hard structural elements of most educational systems. Unfortunately, extrinsic motivation invariably crowds out and, at best, permanently diminishes intrinsic motivation [60,70,71], making the reward or avoidance of punishment the primary purpose of learning. To make matters worse, it could not send a stronger message that an activity is undesirable if a reward is given for its accomplishment, or punishment for failure to accomplish it [60]. One major consequence of this is that an intelligent student, whose intrinsic motivation has been diminished by the reward or punishment, and who has been given every indication that achievement of the grade is the primary purpose for attending, will take the shortest path to achieve it. This in turn leads to cheating, satisficing, and limited risk taking (ibid). It is not surprising that students use generative AIs to assist with or perform such tasks. Simply developing counter-technologies to this is an endless arms race that no one can win [72,73], and all such technologies, from proctored exams to learning diaries or other products that reveal the process, can only ever be temporary solutions that hold until further counter-technologies are available to defeat them. An LLM can easily be persuaded to provide convincing personal reflections or work in progress. Many technologies are available to connect with them in proctored exams, and these will only improve. For every technology we create to prevent cheating, as long as the purpose is perceived as achievement of grades or credentials, counter-technologies will be invented to overcome it.

While ungrading approaches [74] that focus on feedback rather than extrinsic drivers can reduce the harm, as long as credentials remain structurally embedded as the primary purpose of learning, the problem will persist. To break this cycle, any effective structural solution should therefore start with decoupling learning and credentials. There are many ways that this may currently be achieved, even within existing educational models. The Biomedical Sciences program at Brunel University, for example, divides programs into study blocks (courses), which are ungraded, and integrative assessment blocks, that integrate knowledge and skills from across the study blocks and that provide evidence for which qualifications are awarded [75]. Athabasca University provides challenge assessments for courses that permit students to study independently and/or use their existing knowledge that may be used in a similar way. Even within a conventional course, grades may be avoided until absolutely necessary. While the potential for taking shortcuts remains almost as great in those assessments as in courses with tightly coupled learning and assessment, the study process itself remains largely free of such concerns, notwithstanding risks of teaching to the test, and thus it becomes possible to design structures and supports in ways that better support intrinsic motivation, that support risk taking, that allow failure to be intrinsic to the process, that valorize diversity, and that do not need to be so tightly bound to measurable outcomes. Meanwhile, once credentials are decoupled from the learning process, greater focus may be given to making assessments more personally relevant, reliable, authentic, and effective, especially when, as in Brunel's model, the assessments are challenging, useful, authentic, integrative learning experiences in their own right. Other autonomy-restoring pedagogies may help even if structural changes are difficult to make, such as allowing students to have a say in the development of learning outcomes, giving them agency in the assessment itself, or simply designing a process that allows students autonomy in the selection of methods, outputs, or media. Softness for students is a prerequisite for autonomy, notwithstanding that some constraints and boundaries are essential for creativity [76]. The issue is not whether educational systems should be hard but which parts we choose to harden.

Social interaction is also critical to supporting intrinsic motivation, as well as building relationships, modelling ways of being, and addressing many of the broader, softer social goals of education. When teachers (including other students) are engaged with students throughout the process, learning itself (rather than its terminal products) becomes visible, cheating is far less likely and more difficult to accomplish, and students can exercise more control over their learning journeys. If AIs are involved in this, rather than replacing didactic teaching roles they can be trained to facilitate such interactions, prompting connections, weaving threads of conversation together, encouraging dialogue, summarizing discussions, arranging meetings, and so on [77].

Finally, for all of the risks, there is a role for AIs in supporting needs for competence through the development of hard technique, acting as patient, knowledgeable partners able to explain things in ways that a student will more easily understand, offering feedback, providing challenges appropriate to needs, filling in background knowledge, prompting conversations, developing personalized activities, and even (in limited ways) modelling effective practices. Careful prompting and fine-tuning may be needed to avoid risks of encroaching too far into the softer territory that is or should remain the domain of humans, and opportunities should always be sought to ground what is learned in a human, social context. Exactly what those hard techniques they teach might be will vary according to subject needs, and they may include those that GAIs can better do themselves. For example, when we ask an LLM to write code for us, it may help us better understand how to code ourselves, but it raises the question as to why we would bother in the first place. This is a challenge. As our lives increasingly integrate GAIs there will be some skills that are habitually delegated to them, so it may make little sense for those who argue that education should be seen in terms of hard, measurable outcomes to learn them or teach them. Their arguments will be compelling; whether or not we have concerns about the human abilities they therefore replace, education is a preparation for life and, if machines are ubiquitously parts of our lives, it would be Quixotic to insist on learning skills that will never be used. However, it is important to remember the hidden purposes and tacit utility that bring softness to even the hardest of technologies, and the many ways that technologies can be assembled to perform tasks far beyond the intents of their designers. There is intrinsic value to be found in overcoming challenges and developing competence, even when it is something as simple as sawing wood, washing dishes, or playing musical scales with precision, and even when it is something machines could do more cheaply, more effectively, and faster. Each time we lose or fail to learn a hard skill, it shuts down the unprestatable, unpredictable adjacent possibles that it might have provided. Again, this speaks to the central point of this paper: the purpose of education is not the acquisition of skills and knowledge. Those are just some of the means through which it is accomplished. The purpose of education is the development of human beings and the societies they live in.

7. Conclusions

It makes no more sense to avoid using AIs in both teaching and learning than it does to avoid using words. These technologies already are a part of the fabric of our shared, technologically mediated cognition and, whether we like it or not (barring catastrophic disasters), they can and will play substantial roles in what and how learning happens, both formally and informally, in all walks of life. The question is not whether but how they will play those roles. Quite apart from pragmatic and ethical concerns about how they are trained, who owns them, and how they can become less unreliable, AIs pose many potential threats to all aspects of our social, political, and personal lives, from the loss of jobs to the collapse of economies to the end of the human race [78], and much thought is needed to find ways those risks can be mitigated or forestalled. However, though less dramatic, less immediate, and more insidious, the effects on the things that make us who we are—our intelligence, our creativity, our relatedness, our identities—are perhaps the most dangerous of all. If, as they must, AIs affect how and what we learn, it will change us as a species, in ways that (as this paper has shown) may be far from beneficial.

In the first place, there is an urgent need for more research that focuses on the tacit, implicit, and systemic effects of education rather than its effectiveness in achieving intended learning outcomes, so that we are better able to identify changes as they occur. Although standardized approaches to measuring creativity and intelligence may provide some indicators of change, the results of such measures fluctuate for many reasons apart from educational experiences, so they will tell us little. By and large, the effects will be hard to quantify and impossible to replicate because of the situated, complex nature of the process. Soft research approaches such as outcome harvesting [79], appreciative inquiry [80], storytelling, soft systems methods [81], rich case studies, and grounded theory may help to reveal some of the effects of the hidden curriculum, and to help establish baselines against which future learners may be compared.

More broadly, now would be an excellent time to do as many have advocated for over 100 years and re-evaluate the purpose, form, and function of our educational systems. However, educational institutions are deeply entangled with many aspects of societies, any or all of which are mutually hardening, making them highly resilient to major change, at least in less than a generation or two. Although it would be desirable to redesign our institutions from scratch, we cannot simply and unilaterally abandon structural motifs like courses, credentials, timetables, curricula, systems of credit transfer, exams, programs, or rules of attendance, not to mention all of the supporting infrastructure, without instigating an economic and social disaster of unimaginable proportions.

One choice available to us—the easy choice—is to think locally, to solve problems as they emerge in piecemeal fashion, and to develop counter-technologies to address the disruption; legislation, AI-detection tools, increasingly stringent proctoring processes, and so on may indeed put a Band-Aid over holes that appear before they get too large. However, this is, as Dubos [82] put it, a philosophy of despair, as each counter-technology spawns its own counter-technologies in an endless spiral. It would be better to think structurally and globally about ways of embracing rather than resisting the change.

Our best option for now seems to be to find ways to work with AIs as partners, team-mates, and contractors, and to focus on uses that augment rather than replace the things that we most value educationally, personally, and socially; uses where their capacity for soft technique complements but does not replace our own. It would be very helpful if governments and other sources of funding and accreditation that play some of the hardest structuring roles, and that often seem intent on treating institutions solely as economic drivers and creators of productive workforces, focused more clearly on the more fundamental value of education as both a stabilizing and a creative force in society, being one that supports cultural as well as economic goals, and one that makes life better, richer, more rewarding, and safer for everyone. However, even if that does not occur, we can still structure what we already have so that the extrinsic drivers that shape attitudes, processes, and beliefs about education lose some or all of their power. We can seek ways of using our new, tireless partners to connect us, to empower us, and to support rather than control us. We can study, acknowledge, and integrate the changes that AIs bring across the workplace and society, and we can search for, examine, debate, and nurture the sacrosanct spaces, the things that we cannot or should not (at least yet) let go. Radical change wrought by the growth in reach and power of AI is now all but certain, so there is some urgency to this. It is the job of this generation, living at a transition point in the history of the human race, to create structures that preserve what must be preserved, as much as it is to embrace what must be changed.

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Systematic Review

Impact of Social Media on Adolescence: Mapping Emerging Needs to Build Resilient Skills

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Abstract: It is important to study the impact of social media on mental health and well-being, as most young people use social media. Research has provided evidence of the link between social media and mental health, identifying vulnerability variables, risk factors, comorbidity, and predictors of deterioration or improvement. However, there is still very little qualitative insight into young people's experiences and perceptions of social media and its impact on their subjective well-being. This study consists of a systematic review of the literature and a narrative synthesis of scientific articles published between 2013 and 2023 and indexed in the most important scientific databases in our field of knowledge. The SALSA protocol for systematic reviews of scientific literature was followed. We worked on a final sample of 25 articles, all of which were qualitative in methodology. From the content analysis, we extracted five thematic categories that describe and explore in depth the complex impact of social networks on adolescents' well-being. The interactions between positive and negative effects, as well as the links with protective or vulnerability factors, are presented with the aim of constructing as complete a knowledge framework as possible. The paper concludes with useful implications for educational interventions.

Keywords: adolescence; social media; resilient skills; resilient intelligence; mental health; qualitative research; systematic review

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1. Introduction

Social media are digital platforms that allow people to interact by sharing, commenting, and responding to content [1]. As the majority of adolescents use social media, it is important to investigate its impact on their mental health [2]. It is thought that the motivation for using the network and the time spent online could be useful for characterization. It is also worth noting that most patients present with comorbidity between multiple disorders, which further complicates their description and understanding [3].

The concept of 'psychological well-being' reflects the extent to which a person can live a meaningful life in accordance with their deepest values [4]. Mental health has been defined by the WHO [5] as a state of well-being that enables a person to fulfil his or her potential, interact positively with society, and contribute to society. Research in this area is traditionally quantitative, providing evidence of the relationship between social networks and mental health, with limited insight into the experiences and beliefs of adolescents about their use and impact of social networks.

Over the past decade, depression has become more common among adolescents and young adults, according to international reports [6]. Over the same period, the use of social media has also increased. It is neither possible nor relevant to claim that social networking causes depression, anxiety, or addiction. However, there is considerable recent scientific evidence to suggest that social media use can be harmful to adolescents and even younger people [7]. In addition, peer-to-peer online relationships are less satisfying than face-to-face relationships [8]. Studies show that teenagers who spend more time on social networking sites also feel lonelier. Children who already feel lonely may also use social networks more. However, it could also be that using social media makes social relationships worse [9,10].

An alternative theory is that social media is bad for the self-esteem of young people. Exposure to lots of perfect photos online can make teenagers (particularly women) feel bad about their appearance [11]. Depression and further isolation can result from feeling bad about oneself. Key vulnerability factors described in research include earlier age of connection to social networks, having emotional lability, low self-esteem, unstable personality, embarrassment, insecurity, family deficiencies, and poor guidance [12]. Given the high prevalence of comorbidity, mental health professionals question whether addiction is a disorder in itself or a manifestation of an existing primary disorder [13]. For instance, comorbidities have emerged between online dependence and depression, ADHD, social anxiety disorder, and challenging behaviour. In addition, internet addiction in children and adolescents is linked to clinical increases in obsessions and compulsions, deficits in social skills, feelings of being alone, antisocial behaviour, isolation, and, most importantly, the depth of depression [14–16].

Social media also reduces the amount of time that young people have to engage in leisure and other things that help them to be happy, such as exercise and hobbies. They also take their attention away from important tasks such as school, sports, or art. Juggling these responsibilities in order to have time for everything can lead to increased stress and worries about poor time management, given the significant proportion of time that goes into networking [3]. Studies also suggest that late night use of social media interferes with sleep, which for many young people is insufficient and less restful [17].

As explained above, the predominant research in this area to date has used quantitative methodology, establishing the relationship existing between digital environments and psychological well-being, identifying variables of vulnerability, risk factors, comorbidity, and predicting deterioration or improvement. It has mainly been approached from a health care perspective and published in clinical psychology media. However, there is still a very limited amount of qualitative insight into the experiences of young people with social networks and their effects on the subjective well-being of young people. We have not found an in-depth body of knowledge that addresses their educational needs and provides evidence for decision making in our field. In order to contribute to improving the quality of education, the research presented here aims to demonstrate the complex impact of social networking on adolescents' emotional well-being from their own perspective.

2. Method

In this study we followed a systematic literature review methodology using the SALSA protocol for systematic reviews of qualitative studies (Table 1). This is a method for selecting, filtering, synthesizing, and appraising evidence from the qualitative scientific literature [18,19]. It aims to find common views, repeated patterns of behaviour, or concepts across or between qualitative reports [20]. The search starts by looking for articles from the last ten years that have the following key descriptors: 'social networking', 'mental disorders', 'well-being', 'adolescents', 'internet addiction', 'connectedness', and 'bullying'. To make these searches more specific, two Boolean filters (AND/OR) are used to include several similar terms: (1) perceptions/attitudes/views/opinions, (2) adolescents/youth/teenagers, (3) social media/networks/Instagram/Facebook/Snapchat/Tiktok/Twitter, (4) mental health/well-being/anxiety/depression/self-esteem. The following databases were searched: APA PsychInfo, Web of Science, Scopus, and PubMed.

The initial search results are reviewed to remove papers that do not use qualitative methods, or whose internet use is broader than social network interaction. Furthermore, because of the multi-faceted nature of factors related to mental health during COVID-19, those papers that examined social network use during this period were also excluded. Out of 77 documents found, 57 are excluded due to the above criteria and 20 articles are selected for content analysis. After this first register of valid articles, five additional articles are identified from searches in the reference and citation lists of the twenty selected articles.

Thus, a sample of 25 research articles is worked on. The vast majority of the 25 articles are contextualized in Western cultures. Only three of them were studied with samples from Eastern cultures. However, there are common threads in the articles, so that the selection of articles analyzed responds to the interests of an international audience.

Table 1. Diagram of the SALSA systematic reviews protocol for obtaining the sample of articles (self-development).

Search **Research Articles from 2013 to 2023** **Keywords: 'Social Networking', 'Mental Disorders', 'Well-Being', 'Adolescents', 'Internet Addiction', 'Connectedness' and 'Bullying'** **Bolean Operators (AND/OR): (1) 'Perceptions/Attitudes/Views/Opinions', (2) 'Adolescents/Youth/Teenagers', (3) 'Social Media/Networks/Instagram/Facebook/Snapchat/Tiktok/Twitter' & (4) 'Mental Health/Well-Being/Anxiety/Depression/Self-Esteem'**			
APA PsychInfo Documents Found: n = 53	**Web of Science Documents Found: n = 65**	**Scopus Documents Found: n = 59**	**PubMed Documents Found: n = 17**
Elimination of overlaps = 117			
AppraisaL N = 77 Exclusions for: quantitative studies &/OR internet usage not in social media &/OR COVID-19 framework = 57 → N = 20 Added from the references of the 20 selected articles = 5			
Synthesis and Analysis N = 25			

Qualitative findings from each article are coded openly (without pre-determined categories or hypotheses) and recurring themes are identified from content comparison. Narrative categories resulting from the analysis are extracted and synthesized using a thematic synthesis methodology [21].

3. Results

As a product of the whole analytical and synthesis process, five thematic categories are identified (Table 2). These five categories are thought to describe the processes that influence mental disorders and well-being by interacting in social networks over the time frame of this theoretical review. The contents linked to each category are described below with the most relevant bibliographic citations.

Table 2. Name and overview of emerging categories (self-development).

Thematic Categories	Summary Definition
Self-expression and social validation	Adolescents optimize the representation of themselves in social media and feedback from peers usually leads to profile modification. Expectations of validation and impulsive behaviour by publishing are very relevant variables in the study of psychological symptoms.
Overestimation of physical appearance and pursuit of perfect look	The content in social media is predominantly image-based, so the look is very important, affecting girls significantly more. The 'ideal figure' can be especially damaging for people suffering from pre-existing eating-related pathologies. Anxiety regarding dependence on validation is also among the most studied factors.
The stress of constant networking to remain online and its consequences	Social media activity dominates young people's time management and becomes an essential element of everyday life. The idea of disconnecting induces fear, and the risk of social exclusion fuels compulsive use. There has been a reduction in the amount of satisfying time spent with relatives and peers.

Table 2. *Cont.*

Thematic Categories	Summary Definition
Getting involved and supporting each other	Networks can make a beneficial contribution to well-being by helping and getting involved. Online friendships correlate with psychological resilience variables against anxiety, such as perceived support. Also, there are initiatives that aim to promote positive mental health and overcoming fears about seeking professional help.
Facing cyberbullying or models inciting self-harm	Cyberbullying, abusive language, and shaming cause a lot of panic attacks and chronic anxiety in this population. One of the riskiest aspects is the anonymity in which bullies can remain. Another aspect is that episodes are sustained over time. Moreover, exposure to harmful content is frequently described, including publications of self-harm procedures.

3.1. Self-Expression and Social Validation

One of the most repeated themes is that adolescents report the potential of social media to optimize the representation of oneself. Young people are building their identities so that they represent the best version of themselves [22]. Although self-expression is potentially perceived as an exercise in freedom, many admit to the determining influence of others' opinions. Feedback from peers usually leads to profile modification. Although they express enthusiasm when they receive 'Likes' from other users, this pleasurable feeling is short-lived and is followed by sometimes compulsive checks on how many 'Likes' and 'Comments' they immediately receive [23,24]. Adolescents often compare their number of 'Likes' to their friends, so getting fewer can have a negative effect on their confidence and feelings. For teens with a history of fear, distress, or depression, this process increases symptoms [23,25,26].

Posting selfies is a common practice. Girls experience higher expectations of validation when posting and are concerned about, or at least consider, privacy. Boys believe that posting selfies can increase their popularity and admit their desire and need to attract "Likes". They are more impulsive in posting photos and confess to being less concerned about privacy and the appropriateness of the content [27]. Because posting selfies is often a way of validating oneself, there are unspoken codes about how to post selfies, which create an anxious hypervigilance: you have to publish as much as you are visible, which also means not posting too much, lest you be judged [22,26].

3.2. Overestimation of Physical Appearance and Pursuit of Perfect Look

On picture-sharing sites, in which the content is predominantly image-based, the look is very important. Flawless photos with dozens of 'Likes' are a sign of high approval ratings. In this category, there is one factor common to all studies with reference to this topic: gender differences. For girls, 'Likes' are an endorsement of conformity to certain physical standards, which have their roots in the way perfection is portrayed in social networks [28]. Image-based social networks are perceived as being most harmful to their sense of self-worth with a clear gender gap, affecting girls significantly more. In addition, the practice of retouching images is common and fuels expectations of physical idealization. Young people of both genders are aware that celebrity photos are retouched, and yet they continue to conform one's real appearance with those that seem more 'ideal'. It explicitly lowers their confidence, creates unworthiness, and has a negative influence on their perception of their own person [11,29,30]. There are so many of these pictures on the internet that it is very hard not to find them. In addition, it is considered that pictures representing the 'ideal figure' can be especially damaging for people suffering from pre-existing eating-related pathologies, so this practice leads to worsening of the symptom picture [24], as is the case with anxiety regarding the dependence on profile validation.

Although girls feel scrutinized more often, boys also experience criticism and recognize its influence on self-esteem. They report that publishing photos of themselves in genderless or unisex clothes has triggered comments that have questioned their sexuality and have therefore been experienced as negative and limiting to their sense of freedom [28].

3.3. The Stress of Constant Networking to Remain Online and Its Consequences

Young people often describe the way social media activity dominates their time management and becomes an essential element of everyday life. They feel the need for constant interaction, e.g., by taking part in 'threads' of posts, and believing it is necessary to post something daily to maintain a high number of interactions [30]. The idea of disconnecting induces fear, because they fear not being aware of what is happening on networks and feel at risk of social exclusion [22,31,32]. This fuels compulsive use. Constantly picking up their phones and checking multiple social networking apps, one after the other, just for the sake of feeling that they are still connected, is described as a reflexive action [30,31]. The simple gesture of opening the apps again and again induces a sense of calm, with this response resembling that of compulsive checking in some typologies of obsessive-compulsive disorder [33].

On the other hand, there is a widespread perception that there has been a reduction in the amount of satisfying time spent with relatives and peers, causing a sense of disconnectedness with authentic and loved people [34]. Adolescents experience communication problems within the household and realize that personal contact with parents has become impoverished [22]. In addition, to a lesser extent, they report symptoms caused by their use of electronic devices, such as migraines, disturbed sleep, and visual impairment [35].

Thomas et al. [32] investigated the experimental situation of disconnecting from social networks for a whole day. Some respondents were concerned and uncomfortable with the lack of information about their disconnection. Anyone who had been trained for a few hours to disconnect, found it much less anxious, produced higher performance in their activities, and provided more ideas about what to do and who to interact with while disconnected. A common feature in almost all textual accounts of research on this topic is that adolescents talk about their difficulties with online disconnection as if they were talking about other people, not themselves, suggesting they normalize their behaviors, unlike the so-called 'mobile/network addicts'. As a result, they may be avoiding face-to-face contact to the extent that they are utilizing the Internet for socializing and to self-evaluate in a biased way.

3.4. Getting Involved and Supporting Each Other

Young people describe the way in which networks can make a beneficial contribution to well-being, by helping and getting involved. Relationships blossom and grow through tweets, texts, and posts [36]. Several articles reiterate the value of having a digital footprint in creating opportunities for community participation [8,24,32,37]. The argument is that there is a simplicity to making contacts remotely, without the stress of face-to-face meetings. Online friendships correlate with psychological resilience variables against anxiety, such as perceived support [8]. Adolescents quantitatively value their 'friends' or 'followers', and those with higher numbers express that this increases their self-esteem, acting as a variable that validates or demonstrates their popularity. But while having a larger network gives them comfort, they do not always feel that they matter to their 'friends' in networks. Most say that non-networked or 'real life' friends have greater value [8,24].

In this thematic category, as a positive counterpoint to the others, interaction initiatives that aim to promote positive mental health are noteworthy. For example, participants in O'Reilly et al.'s study [30] describe acting on social media in terms of "challenges" to improve their well-being, such as publishing pictures every day of personal sources of inspiration. Next, people invite their contacts to join in by 'tagging' several of them to 'share' the positive message with their peers. Using the network also provides an opportunity to talk about psychological disorders and well-being. They are a good channel for disseminating celebrity recovery stories, which reduces isolation for individuals facing similar experiences and enables those diagnosed to form supporting communities [30,38]. In addition, several studies have demonstrated the benefits of using collaborative chat tools, facilitated by health experts, for people with emotional and behavioral difficulties [39,40].

Users value the huge support network and the secure environment in which they can talk about anything.

Ultimately, it is essential to highlight that these forums provide support in overcoming fears about seeking professional help, providing examples where this first step has helped many people in their recovery [40]. Many young people emphasize the importance of improved counselling in education in order to get the most out of using networks; they need to find reliable information and appropriate groups to join [30,41].

3.5. Facing Cyberbullying or Models Inciting Self-Harm

Despite the benefits of social media, young people report feeling more vulnerable to bullying. In addition, digital content posted to cause harm is estimated to have a very serious effect on emotional equilibrium. One of the riskiest aspects is the anonymity in which bullies can remain, posting offensive messages with impunity as their real identities remain unknown [18,26]. Cyberbullying, abusive language, and shaming cause a lot of panic attacks and chronic anxiety in this population [23]; however, there is a widespread belief that this harmful content is to be accepted, ignored, or tolerated [30,42].

Adolescents who have experienced cyberbullying report a harmful effect on psychological functioning, reporting symptoms such as loneliness and uncertainty [30,43]. While many are aware of the injustice of such content against their dignity, they do not express confidence about the sole responsibility of perpetrators, and many do not know where to turn [43]. When episodes are sustained over time, and certain personal variables are coupled with increased vulnerability, including female gender, the consequences are incredibly damaging, sometimes leading to suicidal or self-harming thoughts and behavior [37]. Some bullies admit to the expressed intention of lowering their victims' self-esteem; these are behaviors that are usually underpinned by jealousy or feelings of threat, inferiority, or dissatisfaction with their own lives [28]. At another level of severity, though not insignificant, subtle harms caused through exclusion are also described, including failure to invite individuals to events, respond to messages, or validate content, with the express purpose of doing harm.

There are also common worries about confidentiality. Despite the fact that you only make your profile public if you want to, teenagers tend to post publicly because they are afraid of being excluded and, once their images have been shared, they are afraid that others will share their photos without their permission. This lack of control induces anxiety, which is made worse by the perpetuation of content after uploading it to the cloud [42].

Finally, exposure to harmful content is frequently described, including publications of self-harm, self-harm procedures, and how to avoid being easily identified by family members or teachers. Strategies are proposed and advice is offered for these practices, which, considering the immaturity of adolescents, are extremely dangerous [7,24,26].

4. Discussion

This article describes the complex impact of networks on the psychological well-being of young people, considering their beliefs, perceptions, feelings, etc. The motivation of the study is to build a current and in-depth knowledge framework on the topic, which serves as a scientific foundation for educational intervention. It is essential to address the effect that the virtualization of social relations is producing in this evolutionary stage from the perspective of its protagonists, in order to be able to adopt decisions that involve both their educators and educational policy and interdisciplinary professional coordination. The methodology used is justified by the need to delve deeper into the relationship that adolescents establish with social networks, from an emergent and non-deterministic perspective.

This discussion is approached from a dual perspective that does not seek to negatively judge the use of social networks, but rather to provide evidence of how their use should be oriented in order to take advantage of their positive potential and reduce their risks. Ultimately, the aim is to achieve responsible and sustainable use. The fact that adolescents talk about mental health in a natural way, to which these channels contribute, is a good start to break down stereotypes and the stigma that many people have mental health problems. However, the qualitative results synthesized in this study support and strengthen the well-known negative effects that new styles of social relations have on health, which primarily affects the investigated population [2].

From the narrative analysis by category, a positive evaluation of the networks emerged, highlighting that they produce and facilitate peer relations and supporting relationships. Digital contacts are, in fact, a mode of social connection that increases feelings of integration and social reinforcement. In terms of their good uses and practices, these channels are seen as spaces for learning from each other, sharing ideas and resources, and dealing with difficulties. In this context, it was striking to find reports of their contribution to health and well-being through participation in groups that share the same mental disorders. In the same way, debate groups, moderated by psychologists, guide discourse on the most common issues, reduce feelings of loneliness, and encourage people to seek professional help from the health system.

However, it has been widely and deeply evidenced that using social media can have a damaging effect on well-being and mental health. Matalí-Costa's findings have been reinforced and extended [3], with other publications detailing damage to self-esteem, and those detailing how emotional harm is more damaging to people with vulnerable personal characteristics [7,33], even provoking or facilitating self-harming and suicidal behaviour [12]. In parallel, the compulsive use of networks negatively impacts how they relate to each other in real life [9,10] or causes insomnia and fears [17]. Another well-documented finding is the negative use of social networks for cyberbullying. Although there is a close link between cyber and in-person forms of bullying, studies have shown that anonymity, the power to spread, and the permanence of humiliating content, generate more extreme levels of victimization and chronicity of anxious-depressive impact on victims.

It is important to note that the resulting thematic categories significantly interact with one another, reflecting the multi-faceted nature of the variables involved. Several of the studies analyzed show opposing descriptions and arguments, with pros and cons of network use, even for the same individuals. For example, there are descriptions of experiences of the positive use of platforms that have generated anxiety about staying connected, fueling addiction. This problem of anxiety about disconnection is one of the most widespread and coinciding problems in the research analyzed.

An important challenge is to move away from viewing adolescents as a homogenous population. This study includes samples of adolescents aged 13–17 years, and it highlights the great diversity within this age group, which magnifies the complexity of digital impact over various psychosocial factors. Everyone has different levels of 'digital skills'. This is crucial for safety and security when using digital tools, such as networks [44]. Livingstone [45] has emphasized that negative impact depends on the intricate interactions between personal traits of vulnerability or resilience and being in protective or stressful environmental contexts, leading to important differences among people subjected to the same networking events or experience. Specifically, self-confidence and competent parenting styles in dealing with social media are considered resilience drivers [46], whereas having a history of any kind of emotional distress makes people more susceptible to social network content and use. In addition, individuals with greater digital resilience may be better able to recognize and reduce the impact of exposure to digital threats. What is important is that people who are prone to affective imbalance outside the digital environment also have a higher likelihood of being at risk online [47]. Therefore, in order to better understand the connection between 'real life' and the circumstances/experiences that worsen mental health in the digital environment, more research is needed.

Drawing on social comparison theory [48], there is a tendency to evaluate one's own ideas and skills by comparing oneself with others. Curiously, this pattern is more common in adolescence than in childhood or adulthood [49,50]. How social networking affects mental health seems to vary from one individual to another depending on the referents used for self-evaluation and the motivation behind their participation in social networks. For example, regarding motivation and type of network use, Appel et al. [9] find that the use of networks from the role of observers who are not very active, predicts attitudes of jealousy and negative social self-evaluation, which is in turn related to a worsened self-concept and depressive state. Moreover, girls have been found to experience higher expectations of validation when posting their photos and content. They are also more concerned about privacy, or at least consider it. Boys believe that posting images of themselves can increase their popularity and admit their desire for validation, sometimes even the need, to attract 'Likes' as validation of their content. However, boys are more impulsive and not as concerned about privacy or the permanence of what is on networks [22,26].

As has long been well known, the most important period for personality development and self-fashioning is adolescence [51], and much of this is currently driven by social media relationships. Given their poor ability to self-regulate and susceptibility to group stigma, teenagers are most vulnerable towards exposure to the harmful consequences of using digital networks and are therefore more likely to become mentally disordered [36]. Placing the evidence in the broader context of how individuals develop cognitively and socially during adolescence helps to provide a window into understanding the processes that determine how networks affect psychological well-being during this period. During the teenage years, the brain undergoes profound changes. The prefrontal area, which is responsible for the resolution of higher cognitive demands, has yet to finish developing in this period, leading adolescents to make decisions through a fast-processing pathway with a strong emotional component [2]. In addition, the nucleus accumbent, which regulates dopamine-modulated reward, is overactive [52]. As a result, young people are highly susceptible to decisions made in the spur of the moment, which poses a problem in the digital world, in which sharing is instantaneous, at the touch of a button. In terms of evolutionary mechanisms, during adolescence, synaptic pruning selects neural networks, which simplifies and reinforces certain patterns of reasoning that will persist throughout life [53], which can lead to an impoverished conception of one's self-image. And, more seriously, this can affect self-injurious and suicidal thought patterns [37].

The results of this theoretical analysis also lead to a reflection on the veracity of Erikson's theory of social development, according to which, at the developmental stage in focus, the greatest stress is due to dealing with two processes intrinsic to the growth of identity: feeling that one fits in with oneself and with the group [51]. In this sense, networks provide a forum to engage in this battle for self-determination, with the context and channels changing at a high speed. For his part, Lewin identifies this stage as a tense life phase characterized by intrapersonal forces resulting from being exposed for the first time to a social environment without parental supervision [54]. This environment, since the emergence of social networks, is duplicated or divided, with a real and a virtual scenario, which could lead to living these dynamics in parallel, constructing two identities, the real and the virtual one. This approach has good and bad connotations. Regarding the positive ones, networked interaction initiatives that aim to promote positive mental health are noteworthy. They are a good channel for disseminating celebrity recovery stories, which reduces isolation for individuals facing similar experiences, and enables the perception of peer support [38]. Users value the fact of feeling accompanied by other people diagnosed with the same disorders. Importantly, these sites encourage people to seek specialist assistance and overcome the prejudice surrounding mental illnesses, providing examples where this first step has helped many people in their recovery [40]. Also noteworthy is their potential for learning, considering that the usefulness and aesthetic appeal of social networks significantly influence learners' knowledge sharing and seeking behavior [55]. The risk is not being sufficiently educated to discriminate appropriate sources of knowledge.

However, as a counterpoint, many adolescents have reported experiencing verbal abuse and being subjected to humiliating comments that lead to crises and chronic anxiety. Furthermore, there is a widespread belief that this harmful content is to be accepted, ignored, or tolerated [30,42]. At another level of severity, though not insignificant, subtle harms caused through exclusion, including failure to invite individuals to events, respond to messages, or validate content, with the express purpose of doing harm, are also described.

This qualitative scientific literature review has underlined the multifaceted implications of social media on young people's well-being. The review has allowed for an advanced knowledge of the reasons underlying the beneficial and detrimental impacts of digital life on emotional well-being. The answer lies in education. A useful framework of knowledge for teachers and school counsellors can be extracted from the discussion. The challenge is to enhance the good that these channels bring and to minimize or mitigate their negative and dangerous effects. An example of this can be found in an educational program developed for secondary education, which uses social networks as a channel to stimulate actions of gratitude with the aim of improving the well-being of students [56]. Educational action should focus on the use of social networks as an additional educational tool. Social networks are used by young people in vital contexts and occupy a large part of their time. There is an urgent need to support with scientific evidence some good practices that are beginning to be implemented in educational institutions by teachers and counsellors. The strongest theoretical reference leads us to consider positive psychology as a basis for designing interventions.

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