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Special Issue Reprint

Higher Education Research

Challenges and Practices

Edited by
Maria José Sá and Sandro Serpa

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Higher Education Research: Challenges and Practices

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Guest Editors

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About the Editors

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Dr. Serpa's dedication to fostering a positive learning environment is evident. He continuously strives to enhance his teaching methods, promoting a student-centered approach that provides a holistic education for an ever-evolving society. He emphasizes the importance of integrating academic knowledge with service to the university and society at large.

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Editorial

Editorial for the Special Issue "Higher Education Research: Challenges and Practices"

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The link between higher education and research is paramount in the current academic landscape. Traditionally, higher education has been envisaged as the cornerstone of scientific development, fulfilling a threefold mission: knowledge transmission (teaching and learning), research (the production of new knowledge) and involvement with society (the application of knowledge for progress). However, the expectations and objectives of higher education stakeholders—including institutions, teachers, researchers, students, policy-makers, and businesses—are undergoing significant changes. We are witnessing a transformation of traditional teaching universities into research-intensive institutions. This trend is characterized by the emergence of research hubs, the emphasis on research that can be translated into applicable knowledge for the benefit of society, and the promotion of partnerships with the business sector, often through the establishment of spin-off companies based on university research [1].

In the current higher education context, marked by an increasing interaction with research and the intensification of internationalization and digitalization processes [2–4], higher education institutions face new challenges and opportunities, such as the initial and ongoing training of teachers, interdisciplinarity and pedagogical innovation, which are critical issues for adapting to the challenges and potential of an increasingly complex and globalized world.

The publication of this Special Issue of the journal *Education Sciences*, entitled 'Higher Education Research: Challenges and Practices', emerges as a contribution to the debate on the ongoing transformations in higher education. This collection of articles explores a wide range of topics within higher education, including the following themes: mentoring and leadership, examining mentoring processes, leadership studies and the intersection between mentoring and research skills; student well-being and success, analyzing student health and well-being, the impact of COVID-19 on the higher education experience and the factors that influence academic research outcomes; pedagogical innovations, exploring problem-solving strategies and active learning techniques (such as educational escape rooms) and fostering innovative teaching cultures; digital transformation, analyzing the digital transformation required by COVID-19 and the role of resource management and training in facilitating this change; student experience and outcomes, examining the experiences of low-income and first-generation students, predicting student retention in catch-up programs and proposing innovative teaching and learning methodologies; social responsibility, exploring the role of public higher education teaching staff in promoting social sustainability.

This Special Issue had a total of 71 manuscripts submitted, of which 18 were accepted for publication after a rigorous double-blind peer-review process. The published articles, which are original, were written by an international community of authors representing a variety of institutions in 17 countries: Australia, Finland, France, Hungary, Italy, Israel, Lithuania, Mexico, Norway, the Philippines, Poland, Slovakia, South Africa, Spain, Sweden, the United Kingdom and the United States.

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The 18 published articles are presented, in order of date of publication (from the earliest to the latest):

Contribution 1 focuses on assessing research self-efficacy and the effectiveness of the mentoring process. The study highlights the importance of understanding doctoral students' perceptions of their abilities and the support they receive from their mentors.

Contribution 2 explores the impact of a competitive environment on military officer cadets' leadership development, team dynamics, and future civilian readiness. The authors examine the role of the 'hidden curriculum' in shaping cadets' learning experiences and outcomes. The study addresses key questions about the influence of competition and informal learning on cadets' personal and professional development.

In contribution 3, a structural model is proposed that emphasizes the role of information literacy and the development of skills in the acquisition of research skills by undergraduate students. The findings of this study can inform university administrators in developing and implementing effective research mentoring programs to improve institutional research performance.

Contribution 4 investigates the multiple dimensions of student health and well-being in an Australian university. The findings highlight the complex interplay between mental, physical, academic and economic factors. The authors advocate a comprehensive and proactive framework to improve student well-being and academic performance.

Contribution 5 uses an ethnographic fiction methodology to explore the lived experiences of higher education lecturers as they navigated the abrupt transition to remote teaching and learning during the COVID-19 pandemic.

Contribution 6 delves into the complex interplay of factors that predict academic research productivity, including gender, research authority, mentoring, collaboration among researchers, self-efficacy and research interest.

Contribution 7 investigates the impact of visual representations on students' epistemological framing when solving a degenerate triangle area problem. The study analyzes how the presence or absence of a triangle drawing influences students' problem-solving strategies and their understanding of the mathematical structure of the problem. By examining students' approaches to a verbally presented problem with and without an incorrect figure, the authors aim to gain insights into how students navigate ill-posed problems.

Contribution 8 proposes a novel approach to competency-based education in instrumental analysis using high-performance liquid chromatography (HPLC). The authors address the challenges of complex instrumentation and limited laboratory time by designing a practical exercise that integrates active student learning with real-world problem-solving. This approach aims to promote the development of essential analytical skills and competencies in a concise timeframe.

Contribution 9 presents a generic multi-level framework for designing educational escape rooms. The authors argue that active learning methodologies, such as escape rooms, can significantly enhance student learning outcomes. They illustrate the application of this framework in a Science, Technology, Engineering and Mathematics (STEM) study program, where an escape room was integrated with a project-based learning activity to create a comprehensive assessment strategy.

Contribution 10 explores the impact of departmental teaching culture on the pedagogical practices of new faculty in a Swedish engineering department. By examining the perspectives of experienced colleagues, the study highlights the significance of understanding and adapting to the prevailing teaching culture. The findings underscore the influence of departmental norms and traditions on the development of new faculty members' teaching styles, emphasizing the need for institutions to consider the role of departmental culture in supporting effective teaching and learning.

Contribution 11 explores the pivotal role of innovation models in stimulating technology-focused entrepreneurship within higher education institutions (HEIs). The authors highlight the challenges HEIs face, including resource constraints, interdisciplinary integration, and intellectual property management. To effectively address these challenges, HEIs are encouraged to cultivate entrepreneurial cultures and forge strong academia–industry collaboration, international partnerships and the integration of entrepreneurship education into technology-focused disciplines.

Contribution 12 analyzes the impact of digital transformation on higher education, focusing on a private university in Spain. The authors examine the challenges and opportunities that emerged during and after the COVID-19 pandemic, particularly in terms of resource allocation and pedagogical innovation. The study highlights the university's increased reliance on online training, videoconferencing tools and accelerated digital transformation initiatives.

Contribution 13 sustains that, within the dynamic context of higher education, the process of academic self-realization is paramount for the individual researcher and the broader academic community. This study sought to disclose the nature of academic self-realization among higher education researchers by exploring the following research question: "What does academic self-realization mean for the researcher in higher education?" The results of the study suggest that academic self-realization involves a process of identifying, developing and manifesting one's unique intellectual and creative capacities within the university setting, thus enriching the personal, scientific and academic dimensions of the community.

Contribution 14 examines the experiences of low-income and first-generation college students. A comprehensive understanding of the experiences of low-income and first-generation higher education students is critical to advancing diversity, equity and inclusion in higher education. Given the significant gap in college enrolment and graduation rates for these populations, particularly in the post-COVID-19 era, it is pivotal to examine the factors that influence their academic success.

Contribution 15 proposes a Bayesian Additive Regression Tree (BART) model to predict student retention rates in tutorial classes. Using a Bayesian approach, the authors aim to quantify uncertainty and improve the reliability of predictions. The study demonstrates the practical utility of the BART model in estimating student retention rates and identifying potential risk factors. The results of this research have significant implications for HEIs, enabling them to make data-driven decisions and implement effective strategies to improve student retention.

Contribution 16 offers a novel STEAM-based approach to teaching cycloidal curves to computer science engineering students. By integrating robotics, problem-based learning and project-based learning, this innovative method aims to increase student engagement and students' understanding of complex mathematical concepts. The authors argue that this approach matches the learning preferences of Generation Z students and proposes a more effective alternative to traditional frontal teaching methods.

Contribution 17 investigates the impact of the COVID-19 pandemic on Norwegian public health nursing (PHN) students' experiences with emergency remote teaching (ERT). The study explores the challenges and benefits of transitioning from traditional face-to-face instruction to online-only lectures. The researchers aim to understand how this shift influenced students' perceived learning outcomes and overall satisfaction with the educational experience.

Finally, contribution 18 puts forth the results of an investigation on the role of public higher education instructors in promoting social sustainability in Ethiopia. The study examines instructors' understanding of their role, their level of engagement in social sustainability activities, and the factors that influence their participation. By analyzing these factors, the research aims to inform policy and practice to enhance instructors' contribution to a more sustainable future.

It is with deep gratitude that we acknowledge the trust placed in us by the authors, reviewers and editorial team of the *Education Sciences* journal. The high level of professionalism shown by everyone involved was critical to the accomplishment of this Special Issue.

In conclusion, the articles in this Special Issue make a significant contribution to enriching the debate on higher education research for the development of Sustainable Development Goal 4—Quality Education.

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List of Contributions

1. Amador-Campos, J.; Peró-Cebollero, M.; Feliu-Torruella, M.; Pérez-González, A.; Cañete-Massé, C.; Jarne-Esparcia, A.; Triadó-Ivern, X.; Guàrdia-Olmos, J. Mentoring and research self-efficacy of doctoral students: A psychometric approach. *Educ. Sci.* **2023**, *13*, 358. https://doi.org/10.3390/educsci13040358.
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Article

Mentoring and Research Self-Efficacy of Doctoral Students: A Psychometric Approach

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Abstract: Effective mentoring is an integral component of the doctoral dissertation process. This study aimed to determine the psychometric properties of two questionnaires developed to assess research self-efficacy and the mentoring/supervision process. The sample comprised 1265 doctorate students (mean age = 32.36 years; standard deviation = 8.20). Items in both questionnaires had adequate discrimination indexes and principal component analysis supported the unifactorial structure of each questionnaire, with adequate percentages of explained variance (47.5% and 60%, respectively). Reliability was good or excellent: $\alpha = 0.71$ and $\alpha = 0.94$. In the research self-efficacy questionnaire, there was a significant interaction between gender and year of doctoral studies. Men had higher scores in the first, second and third years of their doctoral studies than women, but this ranking was reversed for the fourth and fifth years. In the mentoring/supervision questionnaire, PhD students in their first year had a higher score than those in the third, fourth and fifth years, and students in the second year had a higher score than those in the fifth year. Understanding students' perception of their research self-efficacy and the mentoring process is of great importance given the relationship between the mentoring process and students' academic performance and personal well-being.

Keywords: doctoral students; mentoring; research self-efficacy; questionnaires; assessment; psychometrics

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1. Introduction

The roots of the practice of mentoring are found in Homer's *Odyssey*. Mentor (from the Greek Μέντωρ), was the son of Alcimus and faithful companion of Odysseus. When the latter left for the Trojan War, he entrusted the care of his household in Ithaca and the education of his son Telemachus to Mentor. Mentoring is a personal relationship in which an experienced or more knowledgeable person helps a less experienced or less knowledgeable person. Mentoring has a long tradition in business, organizations, health and medical education [1–5] and in junior faculty training [6–9]. In the field of dissertation supervision, mentoring encompasses explicit training in research methods, ethics and procedures and active efforts aimed at ensuring that the supervised students acquire appropriate competences [10].

PhD mentors or advisors (the individual faculty member who directly supervises a student's doctoral research) provide students with personal and professional support and guidance during their doctorate programs and play a central role in the training of doctoral students as scientists and in their success [11,12]. Mentoring of doctoral students aims to prepare students for career success in academia or a related profession. PhD mentors provide students with important feedback on their performance, encouragement when they need it, pragmatic information on how to acquire the necessary skills to succeed in a given field and help open doors to career opportunities. Effective mentoring is an integral component of the doctoral dissertation process [4,13]. Successful thesis supervision is not solely contingent on what supervisors can offer their supervised students; doctoral students must be proactive, receptive to feedback and committed to sustaining the supervision/mentoring relationship. Tenenbaum et al. [14] described quality graduate mentoring as fulfilling three support functions: psychosocial, instrumental and networking. Li et al. [15] explored mentoring experiences and relationships from the mentees' perspectives in a sample of 103 nomination letters submitted for the 12 Jay D. Scribner Mentoring Award recipients who were honored between 2006 and 2016. They found several traits related to being a good mentor: relational (being approachable and accessible, demonstrating humility and genuine care, and being willing to tailor the experience to their mentees' specific developmental needs), instrumental (enrichment of research and writing skills and understanding of institutional rules and practices, including promotion and tenure processes) and psychosocial (helping to cope with the stress inherent in their roles). Creary et al. [16] reviewed 30 articles about mentoring relationships in doctoral nursing programs. PhD students value mentor attributes such as being approachable, respectful and supportive, content expertise and a good communicator.

There are different mentoring models in doctoral programs. Formal mentorship models are those that have become part of the infrastructure of a degree program and are incorporated into the core curriculum. A prime example of a formal mentoring relationship in a PhD program is between the student and their doctoral thesis supervisor. Informal mentoring models are often groups of students who come together to provide support, friendship and guidance during their doctorates. Pancheri et al. [17] noted that collegial support of students in their dissertation phase at a school of nursing provided both social and professional benefit. Lewinski et al. [18] implemented a peer-mentoring program for PhD students at a school of nursing. Students reported post-participation benefits such as getting to know faculty in an informal setting, socializing with students from other cohorts and developing a sense of camaraderie with other PhD students.

Several reports have demonstrated the tangible benefits of mentorship on academic success and the productivity of doctoral students [2,10,14]. In the Graduate Student Well-Being Survey of the University of California, San Diego [19], PhD students were less satisfied (24%) with their mentorship compared to other postgraduates. The satisfied students were more likely to complete their program on time (85%) compared to dissatisfied students (57%). Poorly satisfied students were less persistent and motivated by daily work (35%) compared to satisfied students (62%). In the University of California Graduate Student Well-Being Survey [20], 12% (n = 365) of doctoral students said their advisors did not provide advice and resources in support of their goals and ambitions, 18% (n = 562) said their advisors were not real mentors to them and 8% (n = 262) said their advisors were not an asset to their career or professional development. A 2017 graduate student survey by the journal *Nature* [21] drew responses from more than 5700 PhD students around the world. This survey found that mentorship contributed more to respondents' overall satisfaction with their PhD program than did any other factor. Specifically, guidance from and recognition by an adviser proved to be the top determinant. Evans et al. [22] found that the relationship between principal investigator or advisor and graduate students affects the quality of training in graduate education.

There is a lack of research on the formal mentoring process in doctoral students' supervision. Some instruments are dedicated to the evaluation of the mentoring process, but most of them have been designed to assess general graduate student mentorship functions, roles, behaviors or activities involving undergraduate or general graduate students, but not PhD student mentorship specifically [23–25]. Busch [26] assessed mentoring relationships from the mentees' point of view in a sample of 177 students identified as mentees by their professors using the mentoring instrument Mentees Perceptions. She identified four components: psychological and professional mutual support, comprehensiveness, mentee professional development and research together. With increasing age, mentees reported a decrease in professional development activities. Neither the sex of the mentee nor the sex of the mentor affected these components. Rose [27] designed the Ideal Mentor Scale (IMS) to assess doctoral students' perception of and preferences for a good mentor. Factor analysis of 34 items of the IMS found three subscales: integrity, guidance, and relationship. Rose [28] examined the relationship between students' demographic and academic characteristics (age, gender, citizenship, academic discipline and stage of doctorate) and their preferences for styles of mentoring with the IMS in a sample of 537 students enrolled in PhD programs. She found significant differences for demographic but not academic variables: women scored higher than men did on integrity, international students scored higher than domestic students on relationship and age was inversely related to relationship scores. No group differences were found on the guidance scale. These findings indicate that graduate students' perceptions of the ideal mentor are influenced somewhat by major socio-cultural factors. Schlosser and Gelso [29] constructed the Advisory Working Alliance Inventory (AWAI), a 30-item questionnaire designed to measure the graduate advising relationship from the student's perspective. In a sample of 281 counseling psychology doctoral students, three factors (rapport, apprenticeship, and identification–individuation) were identified. The AWAI demonstrated excellent internal consistency ($\alpha = 0.95$) and test–retest reliability over a 2-week interval ($r = 0.92$). Gedamu [30] designed a survey aimed at exploring graduates' perceptions of the support and direction given by their thesis supervisors. In a sample of 70 Iranian TEFL graduates, he found that doctoral students were very satisfied with the support given by their supervisor (4.08 out of 5 points) and the provision of structure and direction to their thesis (3.93 out of 5 points). Henricson et al. [31] developed a 10-item questionnaire to evaluate expectations of the supervision process when writing a bachelor thesis in a sample of 327 nursing students at a university in Sweden. They found that five factors (the nature of the supervision process; the supervisor's role as a coach; the students' progression to self-support; the interaction between students and supervisor and supervisor competence) explained 74% of the variance. The internal consistency of the questionnaire was 0.68. Smith et al. [32] developed a 44-item instrument, the Collaboration for Leadership and Innovation in Mentoring (CLIM), to quantify important components of PhD student mentorship in nursing at a public state university in the USA. The instrument's overall content validity index (CVI) was 0.91. Test–retest correlations were high ($r = 0.91$) in a sample of 16 nursing PhD students. Ching et al. [33] presented an instrument to measure doctoral students' experiences in a sample of 94 Taiwanese participants enrolled in doctoral programs at two universities. The instrument is composed of three dimensions: career outlook and goal, doctoral experiences and academic identity. The doctoral experiences dimension consists of nine items that loaded in three factors: quality training (two items), career opportunity (three items) and quality advising (four items). Factor loading varied between 0.71 and 0.88; overall reliability was good (alpha = 0.83)

The instruments reviewed have some limitations. They were developed to evaluate mentoring processes in bachelor or in doctoral programs in education, psychology or nursing specifically. To our knowledge, no studies have evaluated the quality of the supervision of the doctoral theses of students from different doctoral courses and disciplines jointly and few studies have reported on the psychometric characteristics of the instruments used, except for the work of Ching et al. [33], although their sample size was small. The purpose of this study was thus threefold: (1) to determine the psychometric properties of two questionnaires assessing research self-efficacy and thesis-related work and the mentoring/supervision of doctoral students; (2) to analyze the mentoring process and its relationship with the research self-efficacy and thesis-related work of doctoral students and (3) to analyze whether there are significant differences according to gender, year of doctorate and funding of doctoral studies regarding the scores for the research self-efficacy and thesis-related work and mentoring/supervision questionnaires.

This study was conducted as part of an institutional initiative, launched in 2018, aimed at assessing and launching an action plan for improving the mentoring and supervision process of doctoral theses and the emotional health and psychological well-being of doctoral students.

2. Materials and Methods

2.1. Sample

The sample comprised 1265 doctorate students (739 women, 414 men, 5 non-binary, 4 others, 22 who stated a preference not to respond and 81 who left the question unanswered), with a mean age of 32.36 years (SD = 8.20, range: 23–67), who were enrolled in one of the 46 doctoral programs in the arts and humanities, health sciences, sciences and engineering, or social sciences and law departments at a large university in Catalonia (Spain) and who completed a survey about emotional well-being, academic performance and the thesis supervision process. The population of doctoral students at this university is 5007. The final percentage of valid responses was 25.26%.

2.2. Instruments

2.2.1. Research Self-Efficacy and Thesis-Related Work

This questionnaire assessed the doctoral students' perceived ability to fulfill various research-related tasks, their work on their doctoral thesis and the availability of resources to carry it out. It consisted of five items rated on a 7-point Likert-type scale (1 = strongly disagree; 7 = strongly agree).

2.2.2. Mentoring and Thesis Supervision Process

The items in this questionnaire describe the characteristics of the mentoring relationship and assess the perception that students have of the mentoring and supervision process of their doctoral thesis by their supervisor. It consists of 13 items rated on a 7-point Likert-type scale (1 = strongly disagree; 7 = strongly agree).

The questionnaires were constructed by three members of the team specialized in the mentoring and supervision of doctoral students and based on the work of Amador et al. [6,34] on the mentoring of junior university professors. Item revisions required several iterations until unanimity by the three members was achieved. The final version of the two questionnaires was approved by all authors of the study.

2.3. Procedure

Participation in the survey was on a voluntary basis. The data were collected through an online version of the survey using the Qualtrics platform. All students agreed to participate in the study and signed an informed consent before answering the survey by clicking the "I agree" option to consent to participate. The whole process of participation in the study, preparation of the questionnaire and data processing complied with General Data Protection Regulation (GDPR) and was endorsed by the university ethics committee. The second- to fifth-year doctoral students received a link to the survey by means of an e-mail sent on 7 February 2022; on 21 February 2022 another e-mail was sent reminding them of the purpose of the survey and asking them to respond, if they had not already done so; on 7 March 2022, access to the survey was blocked. First-year doctoral students were emailed the link to the survey on the 10th of May and a reminder email on 15 June. This difference in timing of the emails was due to the fact that first-year doctoral students can enroll in their doctoral studies until March.

2.4. Data Analysis

The psychometric study of the research self-efficacy and thesis-related work and mentoring/supervision questionnaires involved obtaining the discrimination index for each item via Pearson's correlation coefficient, assessing reliability in terms of internal consistency via Cronbach's alpha coefficient and analyzing construct validity via principal component analysis. The discrimination index (DI) indicates the ability of the item to differentiate between people with low scores on a factor from those with high scores, i.e., people who score high on a particular factor or area should score high on the item and vice versa; if this is the case, the item has good discriminative power. Ebel [35] proposed the following interpretation for the discrimination index: DI < 0.20, the item must be deleted or completely modified; $0.20 \leq$ DI ≤ 0.29, the item needs review; $0.30 \leq$ DI ≤ 0.39, the item is acceptable but should be improved, and DI ≥ 0.40, the discriminatory power of the item can be trusted. These criteria were initially formulated by interpretation of the discrimination index based on differences, although they can be used for orientation in the event that the discrimination index is calculated from a correlation.

Construct validity was studied on the basis of a principal component analysis (PCA). The component extraction technique was fully explored and therefore the main component method was used. The adequacy of the sample size and the assumption of an identity covariance matrix were measured using the Kaiser–Meyer–Olkin index (KMO), Bartlett's test of sphericity (significant chi-square value, $p < 0.05$) and anti-image correlation matrix diagonals (values ≥ 0.05). The KMO values varied between 0 and 1, with higher values indicating a better fit: above 0.90, excellent; 0.80, great; 0.70, good; and less than 0.60, mediocre or unacceptable [36]. Kaiser's criterion (eigenvalue cutoff ≥ 1.0) and the scree test were used to determine which of the emerging factors should be retained. Items with factorial loading ≥ 0.50 were considered sufficiently strong [37].

Reliability (internal consistency) was interpreted as follows: inadequate: $\alpha < 0.60$; adequate but with some shortcomings: $0.60 \leq \alpha < 0.70$; adequate: $0.70 \leq \alpha < 0.80$; good: $0.80 \leq \alpha < 0.85$, and excellent: $\alpha \geq 0.85$ [38].

Pearson correlation coefficients were calculated to explore the associations between the scores of academic performance and mentoring/supervision questionnaires, using Cohen's guidelines to interpret the coefficients: r = 0.10 to 0.29, low; r = 0.30 to 0.49, moderate; r = 0.50 to 1.0, high [39].

Two separate 2×5 (gender $\times$ year of doctorate) factorial analyses of variance (ANOVA) were performed to test whether there were significant differences according to gender and year of doctorate in the scores for the research self-efficacy and thesis-related work and mentoring/supervision questionnaires. Two categories were used for gender, female and male, given the low number of participants who indicated other categories or who declined to respond. As the scores of these questionnaires did not follow a normal distribution, there was heteroscedasticity, and the group sizes were not the same; the factorial ANOVAs were performed with the Wald-type statistic (WTPS) using the GFD package of R [40,41].

Two *t*-tests for independent groups were performed to test whether there were significant differences between doctoral students with funding for their doctoral studies (grouping the options 'full-time predoctoral contract', 'part-time predoctoral contract' and 'industrial doctorate') or without funding in the scores for the research self-efficacy and thesis-related work and mentoring/supervision questionnaires. We chose to perform this analysis separately from the factorial ANOVA (gender x year of doctorate) to avoid unbalanced groups and groups with a small sample size.

3. Results

A total of 1265 students (25.26%) answered the survey; Table 1 shows the demographic characteristics of the sample.

Table 2 shows the items in the research self-efficacy and thesis-related work questionnaire, the DI and the factorial loading for each item. The DI of the items is good. The PCA analyses supported both sampling adequacy (KMO test = 0.773) and the factorability of the correlation matrix (Bartlett's test of sphericity, χ2 (10) = 912.35; $p < 0.001$). The items' factorial loading was high, indicating the adequacy of a one-dimensional solution that accounted for 47.48% of the total variance. Reliability was considered adequate.

Table 1. Demographic characteristics of the sample.

Age, Mean (SD)	32.36 (8.20)	
	n	**Percentage**
Gender (n = 1184)		
Female	739	62.4
Male	414	35.0
Non-binary	5	0.4
Other	4	0.3
I would rather not answer	22	1.9
Marital status (n = 1185)		
Single	552	46.6
Married	225	19.0
Living with a partner	341	28.8
Divorced	23	1.9
Other	44	3.7
Do you have children? (n = 1184)		
Yes	192	16.2
No	992	83.8
Caregiving responsibilities (n = 1179)		
Yes, children and or parents or dependent people	253	21.5
No	926	78.5
Year of doctorate (n = 1116)		
1st	186	16.7
2nd	279	25.0
3rd	262	23.5
4th	199	17.8
5th	190	17.0
Dedication to PhD (n = 1141)		
Full time	852	74.7
Part time	289	25.3
Financing of doctoral studies (n = 1140)		
Pre-doctoral contract	668	58.6
Industrial doctorate	4	0.4
Without funding	378	33.1
Other	90	7.9
Do you have a paid occupation related to the thesis? (n = 1139)		
Yes	398	34.9
No	741	65.1

Note: Some ns do not match due to missing responses for some variables.

The total score of the research self-efficacy and thesis-related work questionnaire is the sum of the item scores. A higher score indicates better perceived self-efficacy. The research self-efficacy and thesis-related work questionnaire had a mean score of 23.12 (standard deviation: 6.23; range: 5–35).

Table 3 shows the items in the mentoring/supervision questionnaire, the DI and the factorial loading for each item. In general, the items had a good DI but the DI of item 1 was only classed as acceptable. The PCA analyses supported both sampling adequacy (KMO test = 0.951) and the factorability of the correlation matrix (Bartlett's test of sphericity, χ2 (78) = 10,522.71; $p < 0.001$). The items' factorial loading was high, with the exception of item 1, indicating the adequacy of a one-dimensional solution that accounted for 60% of the total variance. Reliability was considered excellent.

Table 2. Research self-efficacy and thesis-related work questionnaire, items, discrimination index and factorial loading (n = 1023).

I'm	DI	Factorial Loading
On track to complete my degree program on time	0.507	0.726
Well prepared for the work required to complete my program	0.602	0.799
Upbeat about my post-graduation career prospects	0.450	0.660
Very engaged by my day-to-day work	0.404	0.619
Equipped with the space and the resources I need in the university to succeed academically	0.422	0.625
KMO = 0.773; Bartlett test: $\chi 2$ (10) = 912.35; $p < 0.001$; explained variance = 47.48% α = 0.714		

DI = Discrimination index.

Table 3. Mentoring/supervision questionnaire, items, discrimination index and factorial loading (n = 992).

My Doctoral Thesis Supervisor . . .	DI	Factorial Loading
Expects my research project to be excellent	0.324	0.367
Allows me to set my own priorities	0.612	0.669
Cares little about my work (reverse item)	0.489	0.545
Provides me with advice and resources to support my goals as a doctoral student	0.841	0.877
Gives constructive criticism of my work	0.758	0.805
Is interested in my personal wellbeing	0.765	0.812
Actively participates in my academic and scientific training	0.859	0.891
Devotes time to me and takes my career development into consideration	0.870	0.900
Helps me in my search for opportunities in the academic and professional world	0.809	0.847
Is a support for my career and professional development	0.883	0.910
Impedes the development of my research career (reverse item)	0.537	0.589
Shares information with me about career opportunities inside and outside the University	0.680	0.733
Provides a satisfactory level of mentoring and advice	0.872	0.901
KMO = 0.951; Bartlett test: $\chi 2$ (78) = 10,556.35; $p < 0.001$; explained variance = 60% α = 0.941		

DI = Discrimination index.

The total score of the mentoring/supervision questionnaire is the sum of the item scores. A higher score indicates a good mentoring and doctoral thesis supervision process. The mentoring/supervision questionnaire had a mean score of 66.32 (standard deviation: 17.94; range: 13–91).

The magnitude of the correlation between scores in the research self-efficacy and thesis-related work and mentoring/supervision questionnaires was moderate and statistically significant (r = 0.437; $p < 0.001$; $r^2 = 0.1916$; $n = 986$); thus, the greater the satisfaction with the mentoring/supervision process the greater the research self-efficacy in the doctoral thesis.

Table 4 presents the results of a 2 × 5 factorial ANOVA (gender × year of doctorate) of the scores for the research self-efficacy and thesis-related work questionnaire. As the scores did not follow a normal distribution and there was heteroscedasticity (Levene's test: $F(9, 973) = 1.946$; $p = 0.043$), the factorial ANOVAs were performed with the Wald-type statistic (WTPS). Year was a significant source of variation: students in the first year had a higher score in the questionnaire than students in the fourth or fifth years. But it is important to note that the interaction was also statistically significant, showing that men had higher scores in the first, second and third years of their doctoral studies than women, whereas the opposite was the case in the fourth and fifth years, although the effect size was very small (V = 0.104).

Table 4. Factorial ANOVA of scores for research self-efficacy and thesis-related work questionnaire.

Gender	Year	*n*	Mean (SD)	Source	*df*	*WTPS*	*pWTPS*	*Cramér's V*
Female	1st	112	24.63 (5.79)	Gender	1	1.25	0.267	0.036
	2nd	172	23.19 (5.87)	Year	4	22.56	<0.001	0.076
	3rd	152	22.15 (5.62)	Gender * Year	4	10.57	0.034	0.104
	4th	104	22.71 (6.30)					
	5th	93	22.40 (5.45)					
Male	1st	49	24.76 (6.74)					
	2nd	80	25.20 (6.12)					
	3rd	83	24.29 (6.66)					
	4th	72	21.88 (7.22)					
	5th	66	21.39 (6.78)					

SD: standard deviation; Year 1st … 5th: year of doctorate; *df*: degrees of freedom; *WTPS*: Wald-type statistic; *pWTPS*: significance of Wald-type statistic; *Cramér's V*: effect size.

Table 5 presents the results of a 2 × 5 factorial ANOVA (gender × year of doctorate) of the scores for the mentoring/supervision questionnaire. These scores did not follow a normal distribution and there was heteroscedasticity (Levene's test: $F(9, 943) = 3.756$; $p < 0.001$); as a consequence, the factorial ANOVAs were performed with the Wald-type statistic (WTPS). The only statistically significant source of variation was the year; students in the first year of their doctoral studies had a higher score for the questionnaire than those in the third, fourth and fifth years, and students in the second year of their doctoral studies had a higher score than those in the fifth year, although the effect size was very small ($V = 0.097$).

Table 5. Factorial ANOVA of scores for mentoring/supervision questionnaire.

Gender	Year	*n*	Mean (SD)	Source	*df*	*WTPS*	*pWTPS*	*Cramér's V*
Female	1st	102	71.23 (15.76)	Gender	1	0.01	0.934	0.003
	2nd	169	69.54 (16.40)	Year	4	36.1	<0.001	0.097
	3rd	149	65.09 (17.81)	Gender * Year	4	0.59	0.964	0.025
	4th	100	63.70 (17.70)					
	5th	93	61.92 (20.60)					
Male	1st	47	71.91 (14.30)					
	2nd	76	69.30 (15.74)					
	3rd	82	65.50 (17.29)					
	4th	70	64.49 (19.70)					
	5th	65	59.77 (20.83)					

SD: standard deviation; Year 1st … 5th: year of doctorate; *df*: degrees of freedom; *WTPS*: Wald-type statistic; *pWTPS*: significance of Wald-type statistic; *Cramér's V*: effect size.

Table 6 shows the mean, standard deviation and Student's *t*-test for independent groups for the research self-efficacy and thesis-related work and mentoring/supervision questionnaires, according to whether the doctoral students had funding for their doctoral studies: predoctoral contract (grouping the options 'full-time predoctoral contract', 'part-time predoctoral contract' and 'industrial doctorate') or without funding. No significant differences were found in the research self-efficacy and thesis-related work questionnaire. In the mentoring/supervision questionnaire, significant differences were found between the groups with a predoctoral contract and those without funding; the group without funding had higher scores ($p = 0.007$), although the effect size was very low ($r = 0.003$).

Table 6. Descriptive statistics of the groups of participants with and without funding for the research self-efficacy and thesis-related work and mentoring/supervision questionnaires.

Research Self-Efficacy and Thesis-Related Work								
Funding of Doctoral Studies	***n***	**Mean (SD)**	**Homoscedasticity**		**Student's *t* Test for Independent Groups**			
			F	***p***	***t***	***df***	***p***	**r**
Predoctoral contract Without funding	596 343	23.32 (5.78) 28.80 (6.97)	24.75	<0.001	1.17	611.05	0.243	
Mentoring/supervision								
Predoctoral contract Without funding	577 332	65.48 (17.49) 68.74 (17.28)	2.01	0.157	2.72	907	0.007	0.003

SD: standard deviation; F: value of Snedecor's F statistic; *df*: degrees of freedom; *p*: significance; *t*: value of Student's *t* statistic for independent groups; r = effect size.

4. Discussion

The mentoring and supervision of doctoral students during the period of completion of their doctoral thesis is of great importance, both for the academic achievement of the students and for the quality policy of universities. Preparation of doctoral students needs to be multifaceted and these students can benefit from ongoing guidance during their doctoral research [42,43]. Evaluation of the quality of the mentoring/supervision process is important for the quality policy of doctoral programs, so instruments with good psychometric properties that allow such evaluation are needed.

The first objective of this work was to determine the psychometric properties of two questionnaires that were developed to assess doctoral students' perceived ability to fulfill various research-related tasks and the mentoring/supervision of doctoral students. The items in the research self-efficacy and thesis-related work and the mentoring/supervision questionnaires had adequate discrimination indexes and the PCAs supported the unifactorial structure of both questionnaires, with adequate percentages of explained variance. There are few previous instruments for evaluating the quality of the process of mentoring and supervising doctoral students. Factor analyses of these instruments have found three [26,28,33] or five factors [30] The Henricson et al. [31], Ching et al. [33], Rose [27] and Schlosser and Gelso [29] questionnaires consist of 10, 12, 30 and 34 items, respectively; our questionnaire consists of 13 items that exhibit sufficiently strong saturation on a single factor that explains an adequate percentage of variance [37]. From a practical point of view, a unidimensional measure is important for assessment processes, as its items would reflect a specific construct (in this case the quality of the mentoring process) rather than other specific components, which may have more or less weight in the process. In addition, unidimensional measures allow for the assessment of specific constructs with few items, which is valuable for large-scale research as it reduces the time and effort required from participants. Instruments for the assessment of the doctoral thesis supervision process, such as the one presented in this paper, can be useful both for monitoring doctoral students and for detecting needs and areas for improvement, which could help doctoral programs to train mentors in order to improve the doctoral thesis supervision process.

Several studies have shown the relationship between the quality of mentoring and supervision, the performance of doctoral students, their academic output and their personal well-being [10,19,42,44,45]. The second objective of this work was to analyze the relationship between the mentoring process and the research self-efficacy and thesis-related work of doctoral students. Regarding this objective, it is important to consider that several investigations have shown that the quality of the supervision of a doctoral thesis, the support of mentors, and the style of PhD supervision are key components for a successful doctoral experience and have an impact on the academic performance of doctoral students [10,16,19,42,44,46]. In this work, there was a moderate and positive correlation between the mentoring of the doctoral thesis and the research self-efficacy and thesis-related work of the students.

The third objective of this work was to determine whether there were differences in the students' perceived ability to finish their doctoral thesis and in their evaluation of the mentoring process according to gender, year of doctorate and funding of their studies. We found that first-year students rated their research self-efficacy and their work on the thesis better than those in the fourth or fifth years. However, there was a differential effect according to gender. In the first three years of the doctoral program, men felt better prepared for their work and were more confident about finishing their doctoral thesis on time than women; in the fourth and fifth year of doctoral studies this pattern was reversed such that the women felt more prepared for their work and were more confident than the men about finishing their doctoral thesis on time. One possible explanation for this phenomenon is that students in the final years of their PhD studies feel increasing pressure to publish the results of their research, as the deadline for the completion of their doctoral thesis approaches, and this influences their research self-efficacy and self-confidence in finishing their doctoral thesis within the established deadlines. Different studies have found that men publish more than women over the course of their career, which has inspired different possible explanations for these differences, such as family, sociocultural and academic variables directly related to gender roles. Thus, it is common for women to have family responsibilities [47,48]; greater difficulties in job development and promotion [49]; a greater burden derived from emotional labor [50]; a greater gender gap in productivity during their doctoral studies, which limits their early career stages [51,52] and higher gender-specific dropout rates [53].

Gender and year of doctoral study are other variables that have been related to the assessment of the mentoring or supervision process. Tenenbaum et al. [14] found that women received more psychosocial mentoring and men more instrumental mentoring, while Curtin et al. [10] found no gender differences in the different types of mentoring. In our work we found no significant differences according to gender in the assessment of the mentoring process, although the unifactorial structure of our questionnaire did not allow us to differentiate between different types of mentoring. In relation to the year of doctoral study, students in the first two years of the doctoral program were more satisfied with the mentoring and supervision of their doctoral thesis than students in the last year of their doctoral program. These results are consistent with a report from the University of California [20] in which the percentage of doctoral students who had advanced to candidacy but were dissatisfied with the mentoring process (28%) was somewhat higher than that of doctoral respondents who had not advanced to candidacy (20%). Future research should explore whether dropout rates may be somehow related to these differences found in satisfaction according to year of doctorate study, with the aim of determining whether those students who do not drop out are precisely those who have higher satisfaction with the mentoring process.

The relationship between student funding and academic performance or success is unclear. Some studies have found a positive relationship between student funding and academic success [53], while in others the opposite was found to be the case [54,55]. We are not aware of studies that have analyzed whether having or not having funding for doctoral studies can influence students' assessment of their research self-efficacy and the mentoring process. In this work, we found that students who did not have funding for their doctoral studies gave better evaluations of their mentors and the process of supervising their doctoral thesis than those who had funding. Future research should explore possible relationships between this result and student motivation. It is possible that those students with more intrinsic motivation give a better evaluation of the supervision process and that the supervision itself is a very important aspect of their interest in the doctorate [56].

This work has some limitations. It was a cross-sectional study, and thus provides a snapshot of a process that is longitudinal in nature and may vary over time. The university's quality policy takes this aspect into account and, based on the results of this study, longitudinal monitoring of the personal well-being, mental health, academic performance and doctoral thesis supervision of doctoral students has been implemented, with the aim of promoting policies that favor the personal well-being of students, the quality of supervision processes and the improvement of academic performance.

Regarding the sample, although the sample size was large, it only represents 25.3% of the university's doctoral student population, which forces us to be cautious in interpreting the results since it is possible that those who responded to the survey were the most motivated or most in need of help, which we could not differentiate in our study. Likewise, the percentage of students who have a pre-doctoral contract is higher than usual (58.6%), but they are not all doctoral students at the university. The majority of the PhD students that answered the questionnaire have a PhD contract. This may have influenced the perception of self-efficacy, since it may be related to the availability of time and dedication spent working on the doctoral thesis. A longitudinal follow-up, as mentioned above, which will provide the first data during the 2022–2023 academic year and beyond, may respond to these limitations in the future.

5. Conclusions

The doctoral students' assessment of their research self-efficacy is important for the university; their responses can be used to understand the involvement of these students in their doctoral thesis and thus contrast the information collected through other sources of information within the internal quality assurance system of the doctoral programs. The responses of doctoral students also inform the institution about their assessment of the available resources in the context in which they work on their doctoral thesis and can thus guide policies for the improvement of resources and equipment necessary for research.

Mentoring and supervision processes are important for both doctoral students and supervisors at the university. Our study found that the higher the satisfaction with the mentoring/supervision process, the greater the research self-efficacy in the doctoral thesis.

Gender and year of doctoral studies are other variables relating to research self-efficacy and the mentoring or supervision process. Our results indicate that women feel more confident and prepared than men in the last stages of their doctoral studies (fourth and fifth year). It remains unclear whether this increased research self-efficacy is related to scientific productivity and research career development or could be related to the patterns of their resistance to stress, especially when it has been sustained over time, having to face more stressors throughout their thesis and therefore being better able to withstand the last stages.

Relating to the year of doctoral study, our data indicate that as doctoral studies progress, students are less satisfied with the mentoring by their thesis supervisors, which could influence performance and dropout.

In summary, to our knowledge, this is the first study of the psychometric properties of two instruments that allow the assessment of doctoral students' perception of their research self-efficacy and thesis-related work and the quality of the mentoring/supervision process of their doctoral thesis. Understanding students' perception of the mentoring process is of great importance given the relationship between the mentoring process and students' academic performance and personal well-being.

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education sciences

Article

Agon—Are Military Officers Educated for Modern Society?

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Abstract: The research question in this article concerns how a competitive environment affects the learner's (officer cadet's) personal leadership development and their relationship to their team and with future civilian foundations. More specifically, what are the possible learning effects of the 'hidden' curriculum? This article investigates how more than 250 years of leadership education provides new army officers with new skills and how this environment may affect the cadets' leadership training. The article builds on ethnographic data gathered during the three-year education programme in most of the relevant practical locations and contexts. Data were collected using both interviews and a questionnaire. Regarding trust in their learning environment, cadets reported a mean score of 2.83 on a 1 (low trust) to 5 (high trust) Likert scale, underpinning interview data regarding the lack of trust in the Norwegian Military Academy (NMA) and in their fellow cadets. Cadets also pointed out that competition hindered their learning (mean = 2.50). These findings are interpreted in relation to possible negative effects stemming from internal competition and the evaluation system as a whole. The overall output of this system is a zero-sum game, and thus affects evaluative practices and learning processes. This study is of relevance to higher education officers responsible for designing learning environments.

Keywords: competition; trust; team; evaluation; vocational leadership training; leadership education

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1. Introduction

> *The last thing I felt after the last one and a half years of tactics and practical leadership is that there was very quickly harsh critique if it turned out badly; there was not much emphasis on learning. And there was not much room for error.*
>
> (Cadet informant)

Agon was the spirit (*daimon*) of contest among the Greek gods, and the brother of Nike (victory) [1]. In education, contests can be motivating, but one can also learn that superiority over others can be a token of success [2]. Vocational education can then be viewed as training for specific, narrowly defined jobs [3]—in the present study, becoming an officer in the Norwegian Army. Contests and rivalry will in our case—vocational leadership training—be related to a hidden core of the education, but it is not always explicit or written down in the curriculum. Most of us can relate to this; in American war movies and action-based thrillers, army officers often perform in an authoritarian manner when leading others. This formulates social scripts [4] that affect our thinking about self and others, but also the social interaction among students, between students and the Norwegian Military Academy (NMA) and between the military and society. It is of little use, in army action scripts, if civilians possess higher degrees of education or central positions in society. Equal interaction based on trust falls short in such relationships—and it does not seem to be necessary, anyway. What happens will be as the military decides—interaction can be ordered. That is the way it is on film. What is it like in reality? Is it the case that military officers assume such a super-civilian role for their own reasons, or are they trained for this? If so, this will have an impact on the effectiveness of the cooperation between the military and civilian systems when it matters most. Enhancing a common solidarity mindset between different civilian and military institutions has been formulated as an important goal for society as a whole to handle crises such as a pandemic, military operations, war and other crises [5]. The development of such synergy-oriented and trust-based forms of cooperation is also central to Civil–Military Cooperation (CIMIC) operations. The scope of this research is to reveal how military vocational education can improve for the betterment of society and to identify potential challenges to civilian/military collaborations. These topics are of great importance to the conceptual thinking of total defence [6].

In particular, this is related to the role of the military in creating cohesion in civil society. This does not, however, seem to be the focus of the NMA education, nor can we state that we know that this has been replicated internally at the NMA in any previous studies. In this study, we therefore examined whether higher military education is adapted to the structures of modern Norwegian society, in which societal trust is often emphasised as a key feature [7]. A central premise in our study is that interaction and trust between the military system and society at large is necessary, so that together they can form an effective combined fighting force against any threats that may arise. In this study, we investigated this issue by delving into the educational and professional content at the NMA.

Major General Mick Ryan, the Commander of the Australian Defence College, has recently stated the necessity for the military to gain an intellectual edge, in order to fight future wars [8]: 'The intellectual edge for an individual is the capacity for that person to creatively outthink and outplan potential adversaries. It is founded on the broadest array of training, education, and experience that can be provided by institutions, as well as a personal dedication to continuous self-learning over a long period of time' (p. 7).

Competition between learners within educational practices and simulations can be seen as a widespread and useful method to motivate students or groups of students and to strengthen collaborative learning within higher education [9]. Pennington et al. [10] advised that competition can increase motivation at the firing range. Motivation can be defined as either intrinsic (coming from the inside) or extrinsic (coming from the outside) [11]. Gibb and Dolgin [12] found that the ten top factors influencing the retention of military pilots involved intrinsic factors (i.e., motivation). Kohn [13] problematised competitions in learning by participation in sports, because it can support antisocial behaviour regarding the costs of sharing, helping and cooperation, and a study by Schüler [14] revealed that competition in military exercises seemed to bring to the fore a wickedness in the military, and that this led to unsafe work practices. Liu and Liu [15] reported that because of fiercer competition after entering Chinese military academies, many cadets found it difficult to achieve their own personal wishes. However, as the cadets' motivation was not at the centre of our focus of research in this study, we have not explored this any further here.

Military educational practices can be interpreted as doctrine-driven [16,17], and the development of autonomous teams that are tightly coordinated and highly collaborative is vital in training. To be able to combine forces, the Norwegian training doctrines are related to those of NATO and vice versa [18] (p. 3). For example, the case presented in this paper may have relevance to other military educationalists outside Norway, highlighting the problematic aspect of having individual reward systems and an emphasis on a collaborative learning team at the same time. However, it can also be questioned whether this type of education is adequate to the army officer's central role in collaborations with their civilian counterparts in peace and in conflict. The officers need to communicate and develop relationships with civilian actors while contracting civilian personnel, interacting on research projects and collaborating within 'total defence', when that is called upon. Such areas of collaboration are based on mutual trust developed over time or spontaneous (swift) trust [19,20].

1.1. The Research Questions in the Study

The first research question in this article was: How does a competitive environment affect the personal leadership development of the learners (officer cadets) and their relationships with their teams? The second research question was: How does a competitive environment affect the learner (officer cadet)? More specifically, we wanted to investigate what the possible learning effects of the 'hidden' curriculum, learning that takes place outside the frame of 'official learning objectives', are for both of these research questions.

1.2. The Case and the Context

Since 1750, the NMA has educated officer cadets for service in the Norwegian army. It is the oldest higher education institution in Norway [21]. The purpose of the education at the NMA is to provide students with an individual 'Bildung process' (*dannelsesreise* in Norwegian), wherein each cadet must apprehend the necessary knowledge, skills and general competencies (values) that are required of an army officer [22]. There are ten subjects, of which two are reckoned as core subjects. The two core subjects are professional foundations (PF) (*profesjonsgrunnlaget* in Norwegian) and the leader and leadership development (MLD) course (*leder-og lederskapsutvikling* in Norwegian). The PF subject covers the expectations and *demands of war*. The MLD contributes to the identification of the cadet's individual starting points and needs in terms of development related to the spheres of sociability, personal and professional subjects [22]. An identification of the gap between the starting point and the fully trained officer is stressed as important and is formulated as the starting point of a humanistic Bildung-journey [23].

The division between PF and MLD can be seen as deeply rooted, as well as being a clash of realism and humanism in education. On various occasions, instructors and officers involved in the training repeatedly stated: 'In war there is only one winner!' The quote is interpreted by the researchers as legitimatising the use of difficult means to prepare for the potential hostility of the military vocation. 'Train as you fight' was another quote often overheard in conversations during the fieldwork, underlining a hard and competitive approach. Cadets will eventually depend on each other, and other personnel, when they graduate and enter active duty; however, competition only intensifies as officers jockey for top stratification marks on performance reports and fight for key positions throughout their careers [24].

Besides the grades (A–F) given in the subjects, where an A represents excellent and an F represents a non-passing mark, the NMA also keeps track of the cadets in terms of their suitability to be military leaders (SML]) (paragraph 14.1 and 14.3 in the NMA regulations for education; [25]), and they are rated below norm, a little below norm, norm, a little above norm and above norm. Cadets who perform below norm have failed, and the school council advises the school principal as to whether or not the cadet can continue at the NMA. The other purpose of this system is to promote the *primus inter pares*, the best cadet in the cohort. This position is based on both exam grades and instructors' assessments, which are recorded on a 'secret' Excel scoresheet by the officer who has a special responsibility for the cadet cohort. Inevitably, cadets are ranked from approximately 1 to 50 in this system, with some cadets struggling to reach a norm level, and others competing to be in the top ten or better.

1.3. Learning Outside the Learning Objectives

From a sociocultural perspective on learning, the individual can be seen and understood in light of their surroundings [26]. One of the leading educational scientists today, Gert Biesta [27], has argued that a student entering an educational programme can learn or make valuable experiences outside the narrow frame of predefined learning objectives. He underscored that all teaching implies a risk of not obtaining all learning objectives [28]. Therefore, the unforeseen phenomenon is of importance both in the learning objectives, but also in that students train to cope with situations that are not planned. In such situations, the contract with the learning objectives can be broken [29]. Such situations open learning processes that provide the student with leadership competencies that provide her/him with skills in handling unpredictable and complex situations when they matter the most. Central to this are learning processes based on individual reflections and awareness of relational processes employing trust, involvement and power-free discourses during a crisis [20]. In the next section, we investigate extra-curricular learning within the concept of the hidden curriculum.

1.4. The Hidden Curriculum

According to the U.S. education and curriculum researcher Philip W. Jackson (1928–2015), the activity of teaching contains more than work with a defined curriculum, as the activity of the classroom contains elements of opportunistic behaviour. Jackson [30] (pp. 166–167) writes:

> *As typically conducted, teaching is an opportunistic process. That is to say, neither the teacher nor his students can predict with any certainty exactly what will happen next. Plans are forever going awry and unexpected opportunities for the attainment of educational goals are constantly emerging . . . Experienced teachers accept this state of affairs and come to look upon surprises and uncertainty as natural features of their environment. They know, or come to know, that the path of educational progress more closely resembles the flight of a butterfly than the flight of a bullet.*

The concept of the hidden curriculum, in the process of understanding education, is related to the unexpected and the unforeseen [20] and can be used by an educational researcher to grasp the learning not prescribed in the official curricula. However, there is an underlying assumption that if vital issues are not addressed by the formal curriculum, the cadets may learn from what Jackson [30] denotes as the hidden curriculum. We use this metaphor to address some of the potential learning and unexpected outcomes of the Bildung-journey [31] encountered by the cadets at the NMA.

The main source of evaluation [30] (pp. 20–21) in a school comes from the teachers (instructors), and they continuously make judgements and communicate their assessments to students. Some of the assessments are hidden from the learners (the cadets) when the teachers (instructors/trainers) at the NMA form groups and discuss cadet performance. Part of these discussions also relates to what and how to communicate the teacher evaluation to the learner. Such hidden assessment can convey that the role of the clown [32], who asks questions that cannot be answered or proposes different solutions to practical approaches, is minimised. This is underpinned by research on character strengths among officers and cadets, where creativity is low on the list of priorities [33].

Communication and interaction (*samhandling* in Norwegian) can be seen as vital in leadership [20,34], but so too is the ability to work and perform in teams. Posner and Kouzes [35] underline that a leader's abilities to enable and motivate others to act, to foster collaboration and to get the support of their peers are all important factors related to success.

Being educated as an army officer is an important and all-encompassing activity that takes place at the NMA during a cadet's education. Officer development is the NMA's concept of leadership development for cadets being educated at the NMA. Officer development is consequently the NMA's comprehensive formation process for developing leaders for the Norwegian Army, and it is a central theme in all activity at the NMA [36,37]. The starting point for this officer development is based upon the definitions of leadership and leadership development that are described in *The Center for Creative Leadership Handbook of Leadership Development* [38], where leadership is defined as the process of producing direction, alignment and commitment in collectives. Leadership development expands a person's capacity to be effective in leadership roles and processes. Leadership thus revolves around the development of competencies to direct leadership processes by virtue of being in leadership roles, both formal and informal [39]. This all seems fine in theory, but there may be a difference between theory and practice at the NMA, as there seems to be a hidden curriculum and evaluation taking place, in addition to the theoretical concepts and guidelines that are supposed to govern the NMA.

There might also exist a different understanding among lower and higher levels of the military hierarchy at the NMA about what leadership is and which competences are necessary to lead efficiently. In a study by Boe and Torgersen [40] on strategic leadership competence in the Norwegian Armed Forces Cyber Defence, no common understanding of the term strategic leadership competence was found among the participants. Converging upon a common understanding of this concept would be a first stepping stone that could then be used to enhance ongoing education and competence development in order to face difficult situations as leaders. This might be the case for the NMA as well, as there might be a discrepancy between what the cadets think leadership is and what the instructors think leadership is. If the cadets do not know about the hidden curriculum, they do not know how to act or on what grounds they are being evaluated in their leadership performance.

Complicating this picture further, Torgersen and Carlsten [41] highlighted the importance of preparing strategic military leaders for differing degrees of diversity. Cadets being enrolled at the NMA may come from a variety of different backgrounds and one cannot know if the leaders at the NMA have the necessary competence to deal with this situation.

Also, contributing to the practices at the NMA, role models are linked to the cadets' own leaders, culture and practice [42]. This narrows what is considered valid practice and can enforce a self-driven power structure and a one-dimensional understanding of how leadership should be performed, wherein only people within this culture can be seen as participants. Magnussen et al. [43] have argued that the risks of this NMA practice are related to organisational narcissism and a possible distorted orientation to reality, in which the NMA fails in its given educational tasks related to the needs of society and the future demands of war. In addition, a hidden curriculum, as well as a one-dimensional leadership understanding, may enforce the challenges with what is regarded as acceptable behaviour among the cadets. In a situation of evaluation and the after-action review (AAR), altruistic behaviour and motives can be pressurised. The AAR process in military systems represents some of the most significant mappings of knowledge when it comes to lesson learned/learning from failure in training or operations. AAR forms the basis for detailed improvements of PF, MLD and technological concepts [16].

In addition to the learners being evaluated, the cadets also contribute to peer evaluation during AARs and other formal and informal situations, wherein the performances of the cadets are under scrutiny. Evaluative situations can be recognised by both ambiguity and choice [44], concerning dilemmas about whether to praise or criticise fellow cadets' actions. Such deliberations among cadets can contain considerations of loyalty to the group or cohort of cadets and/or obedience to the system and the military profession and credo. If not naïve, then different levels of rationality and rather complex variations of the prisoner's dilemma [45] can, if played well, optimise the players' performances as a group.

The dilemma showcases the challenges of obtaining the objectives of both performance and safety. Strategies that mimic others, tit for tat, did well in the experiments and simulations of the dilemma in social play, but they were vulnerable to disturbances or defective moves. The remedy for this is pro-social behaviour and generosity [46]. If playing games involving winning or losing, the contest for internal ranking among the cadets with regard to perceived trust can be seen as an important factor in the learning environment.

In this article, the reported effects of unexpected learning outcomes that were experienced by cadets are discussed in the light of the hidden curriculum, the game theory of the prisoner's dilemma [47], and creativity and leadership in team development. At the end of the study, some educational implications are suggested.

2. Methods

This article uses data from the research project 'Practice Makes Mastery?' that took place between 2014 and 2017. This research project is registered at the Norwegian Centre for Research Data (Project number 35059), and other research findings can be found in other research papers; *Pathei Mathos* [48], *Machine Machine* [49] and *Role models and Bildung in Vocational education: A Case Study—The national Military Academy* (Forbilder og danning i profesjonsutdanninger: En casestudie—Krigsskolen) [50]. The data were collected at various NMA practice sites that were used during the three years of officer development and training. The project's ontological starting point was how exercises, as a learning landscape [43], affect officer cadets.

2.1. Ethnography

This research used an ethnographic approach, with a greater emphasis on observation [51] of the cadets' learning and exercise activities than on participation. The data stem from field notes, photos and semi-structured interviews with eight cadets. The cadet enters the learning structure based on his or her status as an individual and part of a team, class and cohort. One researcher (the corresponding author) followed the cadets on their practice field, but did not have what Patton [52] (pp. 340–341) calls an 'inner perspective'. The first author took the role of onlooker. In all situations while observing, the researcher retained his civilian 'outdoor' clothing and was easy to spot among all of the green uniforms. The fieldwork followed the pathways of naturalistic inquiry [53], with an emphasis on 'natural' settings and open-ended conversations. The second and third authors of this research article did not participate in the fieldwork, but contributed to the analysis.

2.2. Informants and Procedure

The contingent of cadets that were the initial 'object of inquiry' consisted of 51 males and 5 females. Their ages ranged from 20 to around 30 years. Out of this cohort, which was followed for all of their exercises, a group of eight cadets, four female and four male, were interviewed. Four interviews were conducted with each cadet: during their first week, and then at the end of their first, second and third year. The end result was that we selected participants on the basis of a grounded theory approach [54,55]. In our case, this meant that our ambition was to obtain a wide variety of experiences, and by that also a relative diversity.

The key informants were picked out by NMA training officers during the cadets' first week of training at the NMA, using the criteria given by the first author such as diversity of years in service, gender, military branch and age. The list of informants was then given to the first author. The research also involved a qualitative and quantitative questionnaire [56]. Just after graduation, an online survey was distributed, and we received 18 responses from the 54 participants (2 cadets were relegated or quit during the three-year programme). Why 36 of the cadets did not complete the survey could be related to the e-mail distribution (i.e., spam filters) or the possible perception of the study as insignificant, or to general survey fatigue. Another factor could be related to revealing the state of internal affairs to outsiders, representing a vocational codex and a wish to keep the problems in-house. This was not investigated further.

2.3. Analysis

Before the final questionnaire was distributed, three out of four interviews with the cadets were conducted. During the final stage of fieldwork, the 'hidden curriculum' of cadet learning emerged. Several informants addressed the significance of the issues of team and trust related to the 1–50 ranking of cadets. This was then integrated in the final interviews and questionnaire; the topics were present already in the second year of education [48]. All interview data were transcribed in MS Word for Windows and collected in MAXQDA 10 analysis software. The interview sets from the final year of education were sorted with MAXQDA 10 into 'competition', 'team' and 'trust'. These three themes were chosen as they were deemed the most relevant in order to answer our two research questions. The two research questions focussed upon competition and the cadets' relationships to the team, and how competition would affect the cadets. In the selected quotes we looked for similarities in word meaning derived from the answers that the informants gave. After the initial coding, the second and third author reread and refined the content of the initial coding. Then, the first author reread the coded material and made the final excerpts. The quantitative answers given by the cadets to the questions related to trust and the effects of competition/ranking on the learning landscape were coded into IBM SPSS 28.0.

2.4. Trustworthiness

Bearing in mind the relatively low number of respondents (18 out of 54), the results give an indication of how some of the cadets (though not all) experienced the effects of competition and trust, and because of this, they may contain a negative bias. It is possible that happy cadets did not bother to reply. Another aspect of the low number of respondents may be related to the vocational codex of not exposing internal 'challenges' to outsiders and exposing the organization's own weaknesses in training to adversaries. This makes not responding the 'safe' solution. The translation [52] from Norwegian into English in this article presented a challenge. It affected aspects such as faction versus fiction and the validity of texts [57], including the communicative validity of the findings and translations. To retain both intention and meaning, the interview excerpts were kept in their 'original' Norwegian form together with the English translation in earlier drafts of the article. This allowed us to preserve the Norwegian voice. Some Norwegian expressions are enclosed in parentheses and remain in the article. To keep the Norwegian voice, we have performed literal translations and have not translated to perfect English 'syntax', and by doing that, the voices of the informants are kept. Photography provides researchers with the opportunity to relive the observed situations with the distance of an onlooker [52]. Questions about the transferability and generalisability of the findings inquire about how they are limited by their 'similarity and fittingness' [53] (p.124). These limitations may be important when we address issues with implications for military training, vocational education, leadership development and learning in commensurate situations.

2.5. Ethical Considerations

This research relied on informed consent from adult participants and was conducted according to the rules and regulations provided by the Norwegian Centre for Research Data (Project number 35059). Information about the scope and ethics of this research was given to the cadets on their second day at the NMA at Tollbugaten 10 (T10) in Oslo, Norway. Anonymity was secured by keeping interviews and name lists on a separate, password-protected server. One cadet withdrew from participation in the project; no reasons were given or sought.

3. Findings

Within the sociocultural framework of learning landscapes [58], a learner (apprentice) is evaluated by how their work is being used (*bruksevaluering* in Norwegian) and the consequences of their learning output (*konsekvensevaluering* in Norwegian). At the NMA, the latter can also be seen as tacitly accepted by the cadets where there are the realistic credos and under the *demands of war*. In the following, cadets' reflections on relegation (being expelled from the NMA), trust and competition are presented.

In the e-mail survey, several cadets expressed that the primary outcomes from the NMA gave them the chance '*to have faith in myself*' and to be '*self-reflective*', while understanding others and caring. One cadet emphasised his need '*to keep a professional identity. This trade demands a lot from us, and to identify with the profession is important in order to grasp our own role in a bigger picture*'. These quotes add nuance to learning outcomes in relation to what other cadets points out. One cadet expressed their learning outcomes this way: '*Keep your friends close but keep your enemies closer.* [There is] *much jealousy, envy, bitterness, and rumours.*' This quote indicates that there is something that the cadet experiences or learns that lies outside the formal curricula—specifically, the hidden curricula. Another cadet wrote:

> *To judge other people's true motives and intentions. Sad, but still true. Instead of creating fantastic communities of mastery, the NMA sets the cadets in opposition to other cadets,*

> *and the cadets against the instructors. This does something to the learning environment, and I think it will affect us all in the years to come.*

This cadet informs us that, within the learning environment, there is something about the organisation of learning that creates tensions among the cadets and between the cadets and the school. In the in-depth interviews, the cadets reflected upon the evaluation and relegation system.

3.1. Cadet Reflections on Relegation and Assessment

One cadet we have called Felicia reflected on evaluation among her peers:

> *Yes, it is just not fair. If he is thrown out (from the NMA), then X should be relegated also. He is better, but he got fewer opportunities to prove himself. Some just stay below the radar, others put their head up and it gets it chopped off.*

Felicia reflects that some of the cadets are not treated fairly, but also that some cadets manage to cope and do not undergo the same scrutiny as others. The system is not perceived as fair. Felicia continues and adds reservations about her viewpoints:

> *There has been a lot of talk among the others in my cohort, and I feel it is not always fair. The evaluation of some of the cadets who are here or not here anymore. I haven't perceived it as fair. But there are also probably a lot of things that I do not know.*

The assessment and evaluations are not always perceived as transparent by the cadets. This could be due to secrecy but could also potentially be due to unclear criteria and personal bias. In an interview, a cadet we have called Karl elaborated on the personal touch or differences among the NMA instructors, but also on how 'second opinions' can be prejudiced. The cadets need to fulfil and pass some obligatory practical leadership tasks, and these tasks may vary in duration and complexity. Karl reflected:

> *It is obvious to me that I have experienced differences between instructors (mentors) in what is evaluated as a pass or fail. I have also felt that if a cadet has been struggling, and there is hearsay in the system that this cadet is struggling and is getting warnings, and is given a new instructor/mentor, I do get a feeling that they are slaughtered unnecessarily. They are looking to see if the cadet makes 'the mistake' and 'yes he did'. So, when it is said to get a fresh look—it is not very fresh. I have experienced that in an order meeting that I felt went okay, but you know that the cadet has received a warning, he is slaughtered straight away.*

In Karl's opinion, the evaluation and relegation processes can be seen in the light of scapegoating. There is one cadet under scrutiny, and the rest are 'off the hook'. However, the AAR and the learning feedback is not all dark. A cadet we have called Nils reflected on the feedback situations: 'No, some instructors are quite good at making out the most important parts. They see the whole process from when the order is given, and they point out my "repetitions" and in a way the most critical errors. And then I feel it is very good. And when they tell me what I am working well, they give me something I can use later.' As Nils reflects, evaluations can be received as valuable if attention is given to the cadets' whole process, and if references to other learning situations they have experienced are also given. However, not everything is always rosy according to Nils, as he continued:

> *But then there are just too many instructors that feel they have to say something just to say something. And if there are three or four instructors that provide feedback, they end up [getting] into many details. They also comment on things that we have no learning prerequisites for to address. It could be parts of my plan that are missing. Sometimes it is the order given that gives the premise for that mistake, and it ends up with too much feedback and too much information. I don't learn anything from that.*

In this quote, Nils noted that the amount of feedback and information given in the AAR needs attention. Another cadet we called Beate pointed to the positives of direct feedback:

During the combat fatigue course I received specific feedback that I did not have time to address before shooting course five in the final year when I had X (head instructor). I tried to jump over a trench, and somebody shot me from the side, and I lay there on my side playing dead. X then stands over me and yells at me. It didn't affect me emotionally or anything because I didn't feel very much, but it was like; hey okay, ah, I shall not run like that, I need to move around it. (Laughs).

After this verbal feedback she reflected on why this fault occurred. Beate continued: 'Everybody had run over and across things, so the people I have been modelling are not perfect either, but this was what I had learnt. But it was kind of nice to get the clear answers: this is not the way to do it, this way is'. To be provided with clear answers and advice was appreciated by Beate. However, all of the mistakes that were not dealt with in earlier sessions had hampered her learning, and probably also that of other cadets in the cohort. This could influence the level of trust between cadets and the NMA.

3.2. Trust and Competition

According to the psychologist Erik Homburger Erikson [59], basic trust is vital in development and learning. Inspired by Erikson and the observed variations of positive feedback in AAR by the researcher, the competitive nature observed at the NMA drew the researchers' attention. Variations on questions that all started 'Do I have complete trust in . . . ?' were asked in the survey provided to the graduated cadets. A 1–5 Likert scale was used. Table 1 provides an overview of the questions and answers related to the trust that the cadets perceived in their learning environment.

Table 1. Perceived trust in the people and in the cadets' learning environment (*N* = 18).

	To What Extent Do You Agree with the Following Statements	M	SD
1.	I have complete trust in my fellow cadets.	3.11	0.83
2.	I have complete trust in my instructors during exercises.	3.22	1.06
3.	I have complete trust in company commanders.	2.94	0.90
4.	I have complete trust in the NMA.	2.83	0.92
5.	I have complete trust in my learning group/squad.	4.17	0.79

Scale ranging from 1 (fully disagree)–5 (fully agree). M = Mean, SD = Standard deviation.

In the vocational education, learning culture and structure at the NMA, cadets report varying degrees of perceived trust (M = 2.83 to 4.17) in their environment. Cronbach's alpha was 0.76, indicating a moderate and reliable level of reliability [60]. This may be seen as a bit odd, as one would probably expect the cadets to have a very high level of trust in fellow cadets, instructors, company commanders and the NMA as an institution to which the cadets belong. We see that the cadets felt the highest degree of trust in their own learning group/squad. The results are from only 18 out of 54 cadets, but when carefully interpreted, the data reveal that there is a breach of trust between the cadets and the NMA. The results follow a *proximo distalis* pattern: while the close unity of the learning group received a mean 4.17 with little spread, the NMA and its mentors and instructors had less positives, but a higher spread, as seen in the standard deviations reported in Table 1. Given the variations in the feedback received on more or less identical performances, we can infer that trust can be affected by the cultivated weight of competition.

3.3. Primus Inter Pares

On the first day of observation, when the cadets were introduced to the research project, they also presented themselves to each other. The most striking impression on the researcher present at that time was that several cadets underlined their own competitiveness, and some also mentioned their gambling. One interpretation of this is that it is a culturally safe behaviour. In a competitive 'elite' school such as the NMA, the cadets are told they are the best on their first day of training. Competition is seen as natural and is used by the

NMA to motivate [48]. Table 2 presents the results of questions relating to the effects of competition on learning using a scale ranging from 1 (fully disagree) to 5 (fully agree).

Table 2. Effects of competition/ranking on the learning landscape.

To What Extent Do You Agree with the Following Statements		N	M	SD
1.	Does competition/ranking among the cadets facilitate learning?	15	2.87	1.19
2.	Has competition/ranking among the cadets enhanced my development/learning?	16	2.50	1.27
3.	Is the ranking of us as cadets motivating?	17	2.76	1.30

Scale ranging from 1 (fully disagree)–5 (fully agree). M= Mean, SD = Standard deviation.

In Table 2, some of the cadets clearly disagreed with the potential positives; however, this view was contested by some of the other participants in the survey. The results indicate that elements of competition have not been experienced as beneficial by all cadets, and competitiveness is perceived as a negative factor in their learning environment. The SML and the use of the 'secret' spreadsheet and a competitive learning culture can be interpreted, after the initial weeks, as fixed. If one cadet exceeds another cadet, leapfrogging them on the spreadsheet, the other cadet is losing their place in the zero-sum game that is created by internal ranking.

3.4. Feedback, Trust and Competition

As noted earlier, there seemed to be variations in the feedback given on different exercises. The cadet whom we called Nils reflected thus on the variations between the different years of study:

> *The last thing I felt after the last one and a half years of tactics and practical leadership is that there was very quickly a harsh critique if it turned out badly, there was not much emphasis on learning. And there was not much room for error.*

In this quote Nils pointed to the potential harshness of the educational culture of the NMA. He claimed that there was an emphasis on playing it safe and reported a shift in the final years when the cadets run the command school in one of the exercises. He continued:

> *But I felt, especially when we run the command school, that there was an emphasis on learning. If you make a mistake, it doesn't count as much, because you have learnt from that and it will be fine the next time. It is a matter of who is in charge.*
>
> Researcher: That the tactician's got a firmer grip?
>
> *Nils: Yes, and one thing is the wording you use. Before the fear of failure was greater, and that fear is not as big the last year, because you are not cut down if you fail. Now it is more like 'good, then you have learnt something. You are attending the NMA to learn'. I remember hearing that [in] the third year. It was the first time, the third year. I got the question '[Instructor] Nils, do you know the difference between this and that? [Nils]—No. [Instructor]—Okay, then I will tell you. [Nils]—Sorry I did not know. [Instructor] No—but that is perfectly fine. You are here to learn.' It was like, what? I hadn't heard that before. So now I feel we can lower our shoulders a bit in the last year. The instructors have withdrawn a bit and given the cadets more responsibility. I can be a little bit more myself now.*

In this quote Nils reflected on changes in the learning environment from what we suggest is in the realm of realism, towards a humanistic approach, with less emphasis on making mistakes matter in the final year. Until then, there was an emphasis on avoiding mistakes and play-acting, hiding who they 'are'. A part of this can be seen considering the SML ranking and the spreadsheet. The cadets are sorted into the top ten, the middle and the 'bottom ten'. The perceived hostility of the learning environment and the instructors' roles in the training were experienced by a cadet we called Klara when she was unwell and could hardly perform. She reflected on her relationship with her official mentor/instructor:

> *He was my mentor [in the] last year. The whole year had passed by, and I was acutely aware that he had lost his faith in me. He didn't think I would make it at all. It showed in everything he said and did. As a matter of fact, he said it directly. During one of the exercises, I was unwell. Couldn't speak a whole sentence without stopping (laughs), I didn't work at all. That was the first time he said something nice to me. He then came over to me and said, 'I really hope you don't pull out of the programme, because I think you are a fine cadet, and I really want you to continue at the NMA'. He put his arm around me and told me he wanted me to continue. It was the first time he had said anything positive to me. It was also the first time he had shown a human side. That he really cared. That he was not only standing on the outside of our team and shouting if anything went wrong.*

In this quote, Klara reflected on the lack of positive feedback and how some 'mentors' openly tell cadets that they cannot complete the course. Together with elements of distrust, an emphasis on competition and avoiding mistakes provides the learners at the NMA with insights from a hidden curriculum [30]. We discuss these findings and their possible implications next.

4. Discussion

One key finding is that there may exist a diversion between the learner's 'inner' contextualisation of the experiences at the NMA and the official NMA discourse [61]. Hence, learners entering the NMA can be provided with educative experiences outside what is in the curriculum [27] and official speeches. Such experiences can be related to a variety of evaluative practices and can be reported as spurious. The system creates its favourites, and they are strengthened throughout the learning processes.

Future higher education should include an ethical responsibility for society and the world [62]. In our study, we believe we have uncovered weaknesses at the NMA on just this point in relation to the interactions in our study, because the cadets perceived a low level of trust and competition was experienced as negative. Supporting evidence for this can be found in Carlsten et al. [63], who showed that the terms used to describe *samhandling* in military doctrines found relevant in education at the NMA were numerous, vague and somewhat overlapping.

This type of vocational learning, with a low level of interaction and high level of competition, can be seen as counterproductive to the aim of creating an ethical responsibility for society at large. In other words, if the cadets do not trust each other or the NMA, how will they be able to create trust in other civilian institutions or others outside the military system? Developing mutual or swift trust [19,41] may be challenging because of how the cadets have being educated during their three years of vocational leadership training at the NMA. The importance of trust has long been recognised [64], especially in military contexts [19]. The cadets perceived as less competent are fighting a continuous uphill battle. In 1943, in the book *The Psychology of Military Leadership* [10] (p.96) the motivational effects from competition were underlined, and it is fair to suggest that this view still is still present [48].

The role of the clown or jester [32] is not wanted by the system. If a cadet's performance in different practical leadership tasks does not match the instructor's view of right or wrong solutions, the cadet is in peril of receiving a negative evaluation. This may hamper innovative solutions, behaviour and thinking. The result of this can also be possibly seen in the low importance the cadets attach to creativity, simply stating that it is not seen as an important character strength for a military officer [39,65]. The system can thus be seen to be reproducing itself through narcissistic behaviour [66], where the clever action is the one that offers a physical and mental match of instructors' personalities and ideals. This also resembles Liu and Liu's [15] point that military cadets are not allowed to be themselves and therefore struggle to reach their personal goals.

The relegation axe looms above the learners, and in our view keeps possible systemic critique at bay. Other ways of thinking and acting, in the learning culture of the NMA that has been described, can be problematic for the students. Creative task solutions, too much individuality or asking questions that address what is unknown [32] can be seen as less street-smart. However, an incremental factor can be that the cadets' placements in the SML ranking can also make it less likely that weaker cadets receive more praise than (in this system) the ones who merit it. The learning outcomes from this can be seen as training to survive in the army's organisational jungle. Cadets learn to survive in the system, and this can be observed to be in harsh contrast with the Bildung journey and the humanistic ideals of self-realisation [67].

Trust can be important in 'tit for tat' games. The system of a 1–50 approach, together with sometimes unclear evaluation criteria, may weaken some of cadets' trust in the NMA and the potential goodwill of the system. Different sides of the learning environment can be seen as conflicting. Hardliners with a realistic approach can make the cadets perform. Hence, if a cadet excels among their peers, others are sinking on the spreadsheet. This can be problematic for teamwork and team behaviour and can cause alliances to form where subtle, and always positive, peer evaluations are provided in the AAR. The competition 'output' can harm the collaboration between the different naval, air and ground forces. More particularly, reduced trust in education can harm collaboration with civilian counterparts, politicians, and the armies of other nations, where interpersonal competencies can be vital. However, it remains open as to how long the butterfly of humanistic ideals can dodge the bullets of the hardliners and the 'realistic approach'. How can the humanistic behaviour and learning the cadets reported in the third year gain influence?

The focus on interaction with different stakeholders/society as a quality factor in higher education has increased [68]. We are not sure if the NMA has taken this into account in their educational curriculum. In addition, what counts as quality in higher education has been addressed by, for instance [69], who reported that the perceived quality factors identified by survey respondents in their study did not align with known and often used methodologies for ranking quality and performance.

5. Educational Implications

One takeaway for educational leaders that emerged from this basic research is related to the need for a less biased feedback culture and finding ways of promoting excellence, other than by a 1–50 ranking approach. A different takeaway is that the lack of trust towards the educational institution itself may be reflected within the military vocation and organisation. The NMA represents more than 250 years of tradition, and possibly mirrors the vocational army culture. Thus, the potential problems with trust at the NMA can also be found in the vocational context. The leadership culture enhanced in training at the NMA does not necessarily promote creativity and individuality, with the risk that the fear of failure overshadows the needs of innovation, as well as the social inclusion of civilian and military collaborations. This training can also have a negative effect when former army officers are employed by civilian associations or companies. The root cause of this potential learning outcome could be related to the hidden curriculum enforced by the NMA. As this study has identified—and to best meet the needs of society, during war, crisis and major challenges wherein collaboration between the military and their civilian counterparts are needed—several aspects of higher military education need revision.

6. Conclusions

In this article, we investigated the research question of how a competitive environment affects the learner's personal leadership development and their relationship to their team.

We also investigated a second research question of how a competitive environment affects the learner (officer cadets). The learners were officer cadets at the NMA going through a three-year education programme to become commissioned officers in the Norwegian Army. Our method of enquiry was based upon collecting ethnographic data in most of the relevant practical locations and contexts during the cadets' three-year programme. Both interviews and a questionnaire were used to collect data. The findings revealed that the cadets experienced a lack of trust in the NMA and in their fellow cadets. Furthermore, the findings also revealed that the cadets experienced competition to be a barrier to their learning. Our interpretation of these findings is that possible negative effects stem from the internal competition at the NMA and from the evaluation system used. The result of this system creates a zero-sum game and can therefore affect the evaluative practices and learning processes in a negative way. Stated differently, it may seem that *agon*, the spirit (*daimon*) of contest among the Greeks [1], may have interfered with the vocational education and learning taking place at the NMA. As a result, the cadets revealed an unexpectedly low level of trust, and this, in combination with a highly competitive environment, might not be the best recipe for educating officers suited to modern society.

7. Limitations

Since this research was performed more than five years ago, the study programmes of the three military academies, the NMA, The Royal Norwegian Naval Academy and the Royal Norwegian Air Force Academy, have been reorganised. There is now a common introductory training program emphasising joint collaboration between the branches. The baseline culture of this 'new' training is, however, related to the military training culture identified in this article; in other words, the problems from the hidden curriculum might even have been escalated by the reorganisation. Further limitations are that this article was based on a single case study and does not say anything about how officer training is performed in other nations' military academies.

Another limitation is the relatively low number of cadets who took part in our study. This must be balanced with the total number of cadets at the NMA and the difficulties in obtaining data from them. As such, our limited sample only gives a snapshot of how they saw the education at the time of data collection, and as a consequence of this, we should be careful in drawing any conclusions related to external validity based upon our sample.

Future studies on if and/or how a competitive environment affects the learner's personal leadership development and their relationship to their team and with future civilian foundations should include all of the cadets from the three years at the NMA, and possibly also from the Royal Norwegian Naval Academy and the Royal Norwegian Air Force Academy as well. In addition, a larger number of questionnaires should be used, including for selective and specific in-depth interviews. These suggestions could strengthen the analyses on this topic.

It would also be very valuable to replicate our study by asking the cadets currently going through the three-year educational programme at the NMA the same questions as those used in our study, given how the educational programme has changed during the past few years. Since 2018, admission to the NMA has been based on secondary school and completed national service [70]. Such a replication study would clarify if the educational programme has changed, and, if it has changed, if or how the cadets' experiences related to trust and competition in relation to the learning environment have also changed.

The need for more research is underpinned in a statement made by Major Kibsgaard [71], a principal lecturer on leadership development at the NMA, who emphasized that there exists a double imbalance at the NMA. The double imbalance lies in the fact that 90% of today's cadets do not have a basic military leadership education when they enter the NMA, while secondly, they have far less access to role models [43], teachers and mentors (professional staff) than the pre-2018 cadets. However, there are still no scientific studies of the hidden curriculum conducted at the NMA in recent years, and there is no scientific evidence of improvement due to educational changes.

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Article

Does Mentoring Directly Improve Students' Research Skills? Examining the Role of Information Literacy and Competency Development

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Abstract: This work proposes a structural model highlighting the research skills of undergraduate students. Due to the stages in their research project implementation, mentoring students becomes a crucial initiative in higher education institutions. Despite substantial progress in the literature linking mentoring and skills development, there is a lack of greater emphasis on research skills, especially for undergraduate students facing research work for the first time. Consequently, the direct relation between mentoring and research skills may not be straightforward. Thus, driven by social learning theory, the proposed model highlights the mediating effects of information literacy constructs and competency development on the relationship between mentoring and research skills. An empirical study of 539 participants via Partial Least Squares–Structural Equation Modeling supports six of the seven hypothesized paths. Three major theoretical contributions arise from the findings. Firstly, mentoring improves information-seeking skills and information-sharing behaviors and facilitates students' competency development due to the technical knowledge transfer from the faculty mentor to student mentees. Secondly, information literacy constructs and competency development promote research skills, emphasizing that students with those behaviors and capacities will achieve enhanced research skills. Finally, our findings suggest that mentoring does not directly translate to improved research skills; instead, information-seeking and sharing behaviors and competency development fully mediate such a link. Thus, mentors must shape these behaviors for mentoring to develop students' research skills. Theoretical and practical insights are outlined from these findings for university leadership to inform the design of mentoring initiatives for undergraduate students.

Keywords: mentoring; research skills; information seeking; information sharing; competence development; undergraduate research

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1. Introduction

The active involvement of undergraduate students in scientific research yields numerous advantages for their academic and professional careers [1]. Engaging in research improves students' propensity to publish in high-impact research journals, experience professional fulfillment, and achieve greater economic and academic stability [2]. Barnett [3] argued that undergraduate research and inquiry are crucial for developing higher-order skills and academic dispositions that prepare students for the complexity of modern society and the economy. This growing consensus emphasizes the need for learning opportunities, prioritizing research and inquiry-based learning. Typically, undergraduate research projects involve multiple stages, such as conducting a literature review, devising a research plan, collecting and analyzing data, and presenting the results in a thesis manuscript, journal article, or conference proceeding. Throughout the research process, students typically receive various types of mentoring support, which could be formal or informal, and students can derive benefits from having multiple mentors who offer diverse forms of support [4]. Mentoring undergraduate research has been recognized as a highly effective practice that enhances the quality of education and learning in higher education [5,6]. Among those pivotal practices is the faculty-mentored undergraduate research experience, in which students collaborate with expert faculty mentors on discipline-based research activities [7]. However, mentoring extends beyond the formal faculty and undergraduate student relationships, which can involve various individuals (e.g., university staff, peers, family, and friends) and can occur in either one-on-one connections or small group settings, all of which contribute to student's educational success [8–10]. In the work of Mullen and Klimaitis [11], they differentiated mentoring from coaching, induction, or training. They emphasized that mentoring is an active process, not therapy, a unilateral endeavor, a panacea, a temporary fix, or a singular intervention. Some manifestations include providing students with written feedback on their thesis manuscripts to improve their academic writing [12]. Also, regular one-on-one consultations between mentors and students, including verbal feedback, result in successful thesis completion and higher student satisfaction [13]. During mentoring, a complex process of communication, collaboration, conflict, and understanding of mentor–student interactions occurs [5]. The complexity of the mentorship experience in undergraduate research is augmented by the students' emerging self-development [5].

Mentorship is a symbiotic relationship where the faculty mentor fosters the student's growth professionally and personally, offering opportunities for professional skills development, networking, and confidence [14]. Extensive research has been conducted over the past three decades on the benefits of mentorship [15]. However, despite significant milestones in the field, Crisp et al. [16] acknowledged that the definitions of mentorship had been a subject of debate and evolution over time, demonstrating the intricate nature of understanding and defining mentorship. Gershenfeld [17] found that the primary function of mentoring is academic support, followed by psychosocial/emotional support and role modeling. Mentoring aims to enhance skills and abilities, providing broad support and focusing on individual growth and achievement [18,19]. Studies in the domain literature found that mentoring can improve information-seeking skills, influence information-sharing behavior, aid in competency development, and improve research skills by providing guidance, support, and feedback [5,20–22]. Case [23] associated information seeking with the actions carried out to find information that meets the information requirements of individuals in their everyday undertakings. Lopatto [24] and Russell et al. [25] argued that mentorship in undergraduate research goes beyond faculty members, which suggests that other research staff, academic librarians, postdoctoral fellows, graduate students, and undergraduate peers play important technical or psychosocial roles in this process. For instance, Blaney et al. [26] highlighted the critical aspect of cascading mentorship, where senior students and staff, with postdoctoral fellows (or postdocs) as a case in point, mentor graduate students in laboratories. Their findings emphasized the hands-on support and troubleshooting students receive from postdocs, which significantly impact students' mental health. Chlomoudis et al. [27] observed that students seek information to improve their academic or professional performance. In consonance with other information and communication technologies, the internet has accelerated this process. Along this line espouses the criticality of information literacy as it involves identifying, retrieving, evaluating, and using information effectively, which are crucial for successful information-seeking skills. Research on information literacy and information seeking can help individuals develop strong information-seeking skills essential for conducting high-quality research and achieving academic and professional goals [28].

Meanwhile, information sharing can improve research skills by enabling knowledge exchange, mutual learning, and collaboration. Mentees can gain fresh insights and diverse perspectives that can aid in refining research questions, creating more robust designs, and generating innovative and impactful findings. With effective and consistent mentoring initiatives, students develop varying degrees of competence. Competence is the ability to handle specific situations or tasks successfully. Its requirements will change with several factors, such as internationalization, new production methods, and the widespread implementation of information technology [29–31]. Competency development integrates skills, knowledge, and job attitude to achieve desired workplace behavior and performance and can be formal or informal, with the latter regularly occurring during work and characterized by a lack of focus on learning [32–35]. The relationship between undergraduate research and mentorship is an area that has received significant attention in academic literature. While there is some evidence to suggest that mentorship can positively impact undergraduate research skills, there is still a need for further exploration of this relationship, as previous findings were not too straightforward.

This study seeks to address the existing gap in the literature on mentoring by empirically investigating the influence of mentorship on the development of undergraduate students' research skills, using Bandura's social learning theory as a guiding framework. Bandura's social learning theory provides a theoretical lens for mentoring, suggesting that learning occurs in a social context through observation and modeling. Mentees look to their mentors as role models to develop new skills or gain knowledge from a mentoring relationship. The mentor demonstrates the skills and provides motivation and expectations for the mentee [5]. When the mentor is regarded as a role model, the mentee gains confidence, self-efficacy, and exemplary job performance [36]. While the mentoring approaches may differ, the main goal remains the same: for the mentor to act as a useful example for the mentee's progress. With insights into critical factors in developing research skills, this work explores the relationship between mentorship, information-seeking skills, information-sharing behavior, competency development, and research skills. The study aims to (1) develop an empirical model to demonstrate how mentorship contributes to the formation of information-seeking skills, information-sharing behavior, competency development, and research skills; (2) test the model with empirical data using Partial Least Squares–Structural Equation Modeling; and (3) examine the mediating effect of information literacy (i.e., information-seeking skills and information-sharing behavior) and competency development on the relationship between mentoring and research skills.

Furthermore, this study offers theoretical contributions. First, this work provides a better understanding of the mentorship's role in enhancing research skills by applying Bandura's social learning theory and testing its applicability to the model in explaining research skills among undergraduate students. This theoretical contribution advances our understanding of how mentorship can impact research skills. Second, this work offers insights into how mentorship can enhance undergraduate students' research skills. The findings of this work could provide insights into developing educational and training programs that aim to improve research capabilities among undergraduate students. Theoretical contributions of this work hold significance in developing countries, such as the Philippines, where the development of research skills among undergraduate students has become increasingly important. This study sheds light on the role of mentorship in developing research skills, which can help universities in the Philippines and other similar countries craft effective mentoring strategies for enhancing research skills among their students. Moreover, the practical implications of these theoretical contributions can be extended to universities worldwide. The insights provided by this study can guide university administrators in designing and implementing effective research mentoring programs that can enhance the research performance of their institutions. The knowledge gained from this study can help universities build a pool of skilled researchers who can advance an understanding in their respective fields and positively impact society.

The rest of this paper is arranged as follows: Section 2 outlines the review of the relevant literature and hypothesis development that guides the proposed structural model. Section 3 describes the study methods, including sampling and data collection, the profile of the participants, and data analysis. Section 4 reports the results of the measurement and structural models. Section 5 discusses the study findings and their insights. It ends with some concluding remarks and pathways for future works in Section 6.

2. Literature Review and Hypotheses Development

2.1. Bandura's Social Learning Theory

Bandura's social learning theory highlights the influence of social interactions on shaping a person's characteristics, behaviors, and skills, emphasizing the role of performance feedback and modeling persuasion [37]. It was deemed the first to include "modeling" or "vicarious learning" as a form of social learning [38,39]. Social learning theory acts as a link between behaviorism, which focuses on modifying external behavior through reinforcement and repetition, and cognitive theory, emphasizing the cognitive aspects of learning beyond routine memorization [37]. Furthermore, self-education and self-development play a crucial role in this process, involving self-regulation and the ability to guide oneself, make choices, and navigate challenges, including moral conduct [40–42]. In the context of social learning theory, Edinyang [38] established the difference between "imitation" and "modeling". Imitation is the learner's capability to reproduce observed behavior, whereas modeling involves a more intricate process with four crucial steps to facilitate successful observational learning. Bandura [42] outlined a process by which people learn through modeling and observation: (1) observing behavior, (2) internalizing it through cognitive processes, (3) replicating it through personal actions, and (4) receiving positive feedback to enhance motivation and self-efficacy, leading to improved performance, especially for individuals with high self-efficacy. Bandura [41] asserted that the presence of these components is pivotal in influencing whether or not imitation occurs when exposed to a model.

2.2. Mentoring

In the context of undergraduate research projects, mentorship is a more bonded and symbiotic relationship in which the faculty mentor fosters student growth professionally and personally [14,43]. In a mentoring relationship, mentees consider the mentor a role model for developing new skills or gaining knowledge. The mentor demonstrates the skills and provides motivation and expectations for the mentee [5]. Mentoring offers professional skills development, networking, professional values and attitudes, and confidence [14,44]. It is considered a critical approach for developing research skills and promoting faculty success [20]. Symbiotically, mentoring is an efficient approach for emerging researchers to understand better how academics conduct research, enhance their research skills, and build confidence in advancing their research interests [21]. Although mentoring approaches may differ, the main goal is for the mentor to serve as a valuable role model for the mentee's growth. The primary objective of mentoring is to enhance skills and abilities, which requires accommodating various interpersonal styles and expectations [21]. Jacobi [18] identified three aspects of mentoring: (1) focus on individual growth and achievement, (2) broad forms of support (i.e., professional and career development), and (3) the personal and mutual nature of mentoring relationships. Luna and Cullen [45] pointed out that mentoring relationships could take various forms, such as informal or formal, short-lived or long-term, and can be either planned or spontaneous. Furthermore, Mullen and Klimaitis [11] provided an overview of the nine diverse classifications of mentoring alternatives derived from the empirical literature on educational mentoring. Recent works on mentoring focus on peer mentoring or cascading (see Blaney et al. [26]; Lorenzetti et al. [46]) and virtual or e-mentoring (see Tinoco-Giraldo et al. [19]).

In mentoring, a mentor can assist an individual in identifying and prioritizing their information needs and developing effective strategies for discovering and assessing information. A mentor can also provide feedback on the quality of the information, allowing the mentees to improve their information-seeking skills [20]. For instance, a mentor could introduce mentees to new sources of information and alternative research methods, broadening their understanding of the research process and assisting them in developing a more sophisticated approach to information seeking. Also, mentoring influences information-sharing behavior by creating a supportive environment where people feel comfortable sharing their knowledge and experiences with others [21]. Individuals may become more confident in their abilities and more willing to share their insights and perspectives with the help and encouragement of a mentor [20]. A mentor may also demonstrate the value of sharing knowledge and expertise with others by modeling positive information-sharing behaviors. Mentoring can help build more robust and collaborative students by fostering a culture of information sharing, where individuals can learn from one another and achieve their goals together. Also, mentoring supports competency development by providing guidance, support, and feedback as they gain new knowledge and skills [5,11]. A mentor helps identify areas in which mentees need to improve their competence and can provide resources and support to achieve their goals. For instance, mentors can provide valuable perspectives and guidance by sharing their own experiences and insights, assisting the individual to overcome challenges and progress in their development. This may boost the mentees' confidence and self-efficacy for continuous growth and improvement. Overall, mentoring can be an effective tool for promoting competency development and assisting individuals in reaching their full potential. Consequently, mentoring improves research skills by providing guidance, support, and feedback throughout the research process [22]. For instance, mentors offer feedback, identify areas for improvement, and provide encouragement and motivation.

Several studies emphasized the influence of mentoring on the performance of undergraduate students in the research context. Haege and Fresquez [47] explored the effects of mentoring strategies. They examined their impact on student success and academic skill development by focusing on a diverse population of students at a public, minority-serving institution. Palmer et al. [5] analyzed the intertwined relationships between mentoring, undergraduate research, and student identity development, focusing on the outcomes of mentored undergraduate research to better understand the relationships and develop a research agenda that informs the practice of mentoring undergraduate research in higher education. Furthermore, Agricolo et al. [48] analyzed mentors' diagnostic behavior by outlining various traits that mentors use to assess students' research skills. Nolan et al. [49] examined the benefits and barriers of undergraduate research experiences in statistics from the perspective of students, faculty mentors, and institutions. Thus, mentored research benefits diverse students and does not affect their timely graduation rates. The quality of mentoring, including socioemotional and culturally relevant mentoring, and the duration of the mentorship influence students' learning and development during research experiences [47]. Blaney et al. [26] focused on cascading mentorship, which sheds light on the distinct mentoring role of postdocs and explores the nature and potential outcomes of interactions between students and postdocs.

Nevertheless, several studies have explored the relationship between undergraduate research and mentorship. Some of these studies have found that mentorship can improve undergraduate research skills like critical thinking, problem solving, and communication. For example, Laursen et al. [50] discovered that undergraduate students with mentors reported higher research skills than those without. However, while the relationship seems straightforward, it is important to emphasize that the findings of several studies disagree on the relationship between mentorship and undergraduate research skills. For instance, Malcom and Feder [51] found that mentorship had little impact on the development of undergraduate research skills. This suggests that the relationship between undergraduate research and mentorship is complex and may be influenced by several factors, including the quality of the mentorship, the student's prior research experience, and the specific research project. Thus, while some findings suggest that mentorship positively influences undergraduate research skills, there is still a need to investigate this relationship further to understand better the factors that influence the efficacy of mentorship and the specific strategies by which mentorship impacts undergraduate research skills. Exploring this relationship can be useful for promoting research skill development and assisting students in academic institutions achieve their research endeavors. With these, the following hypotheses are offered:

Hypothesis 1 (H1). *Mentoring positively and significantly affects students' information-seeking skills.*

Hypothesis 2 (H2). *Mentoring positively and significantly affects students' information-sharing behavior.*

Hypothesis 3 (H3). *Mentoring positively and significantly affects students' competency development.*

Hypothesis 4 (H4). *Mentoring positively and significantly affects students' research skills.*

2.3. Information-Seeking Skills and Research Skills

Students are often faced with challenges and difficulties throughout their university stay. In response, their help-seeking skills are considered a deliberate act of seeking assistance, guidance, or support [52–54]. Help-seeking among students involves actively seeking solutions from others to address their problems, acting proactively to avoid a potential failure, and enhancing independent learning, ultimately leading to improved academic achievement [55,56]. In many cases, help-seeking behavior involves information-seeking skills. For instance, when students seek help, they often require specific information to understand better and find appropriate solutions to address their needs more effectively. Chlomoudis et al. [27] observed that students seek information to fulfill their information requirements, which, in turn, enhances their academic or professional performance. Information need is an individual's recognition that their knowledge is inadequate to attain an objective, while information behaviors encompass all forms of intentional and unintentional information-seeking patterns [57,58]. Information literacy is identifying information needs, identifying and retrieving relevant information, and evaluating and using information effectively and efficiently [59]. Furthermore, information literacy is an individual's ability to identify the need for, search for, evaluate critically, and use the information to solve problems in diverse situations [60]. Research on information literacy is closely linked to the study of information-seeking behaviors. A considerable body of literature investigates how students seek information in the context of learning and information literacies (e.g., [60,61]). The advent of the internet has accelerated information seeking [62].

Accordingly, information literacy research focuses on expressing information-seeking skills and educational outcomes. Wilson [63] proposed a nested model that partitions information behavior research into distinct subfields. The primary field is information behavior, within which the study of information-seeking behavior examines individuals' diverse techniques to discover and obtain access to information sources. Within the broader domain of information-seeking behavior, information-searching behavior is a subset that concentrates specifically on the interactions between computer-based information systems and information users [64]. In an academic setting, seeking information is an essential component of the tasks given to the students. Students are expected to actively engage in the information-gathering process to draw conclusions based on information from various sources [65]. The critical characteristics of information seeking are the availability of various alternatives and the student's responsibility to find the required information. In a learning context, information behavior related to tasks is frequently imposed to elicit expected learning outcomes [65]. Howlader and Islam [66] revealed that most undergraduate students require academic- and employment-related information. As a result, they frequently visit the library to perform research work and study for competitive job exams. According to Singh et al. [62], how undergraduates search for information within an academic environment involves searching for, assessing, choosing, and utilizing information for educational and academic objectives. Thus, information-seeking skills are an important aspect of the research process, and individuals with strong information-seeking skills are better equipped to conduct high-quality research. Students are expected to identify and find relevant information from various sources to conduct effective research. This necessitates information-seeking skills such as defining research questions, developing search strategies, evaluating sources for relevance and reliability, and synthesizing and analyzing information. Thus, we propose the following hypothesis:

Hypothesis 5 (H5). *Information-seeking skills positively and significantly affect students' research skills.*

2.4. Information-Sharing Behavior and Research Skills

Moore [28] defined information sharing as the exchange of relevant and timely information, both formally and informally, among participants (e.g., students). Bălău and Utz [67] argued that due to the proliferation of online collaborative platforms, it is essential to understand and effectively manage the dissemination of information in the present-day knowledge-based economy. Cho et al. [68] aimed to clarify the process of sharing information and to explore the internal and external motivators that may encourage individuals to share information on Facebook. Information-sharing behavior influences research skills by providing access to a broader range of ideas, perspectives, and resources. For example, when students share information, they can exchange knowledge, mutual learning, and collaborative efforts to achieve shared objectives. This facilitates the students in gaining fresh insights and diverse perspectives that can aid in refining their research questions, creating more robust research designs, and generating innovative and impactful findings. Thus, the following hypothesis becomes relevant.

Hypothesis 6 (H6). *Information-sharing behavior positively and significantly affects students' research skills.*

2.5. Competency Development and Research Skills

Competence is the ability of an individual to successfully handle certain situations or complete a specific task or job [29]. Adler [30] and Brown et al. [31] highlighted that the aspects of competency will change and become more rigorous due to several factors, such as globalization, the advent of novel production techniques, the extensive use of information technology, and the increasing significance of knowledge-based production in different organizations. Competency development integrates skills, knowledge, and job attitude to achieve the desired workplace behavior and performance [32]. Forrier and Sels [33] defined competency development as the actions undertaken by the employee and the organization to preserve or improve the employee's functional-, learning-, and career-related competencies. Competence development in organizations can be divided into two categories: formal learning, which is planned and organized with certification, and informal learning, which occurs regularly during work and everyday life with a low degree of planning and organizing. While formal learning is popular, informal learning occurs while primarily performing another task and is characterized by a lack of focus on learning [34,35]. Analogously in an academic setting, students' competence in carrying out undergraduate research projects stems from formal and informal learning, with a strong emphasis on the former. Universities design programs and allocate resources to develop students' skills in identifying critical research questions, seeking information sources, designing research methods, synthesizing research findings, and disseminating project results. In addition, mentors and fellow students within and outside the institution help students gain competencies, including desired attitudes, in performing research tasks. On the other hand, students' access to the internet via video-sharing, e-learning, and even social networking platforms provides vast opportunities for increased research competencies. Thus, we propose the following hypothesis:

Hypothesis 7 (H7). *Competency development positively and significantly affects students' research skills.*

The proposed structural model and its hypothesized relationships are shown in Figure 1.

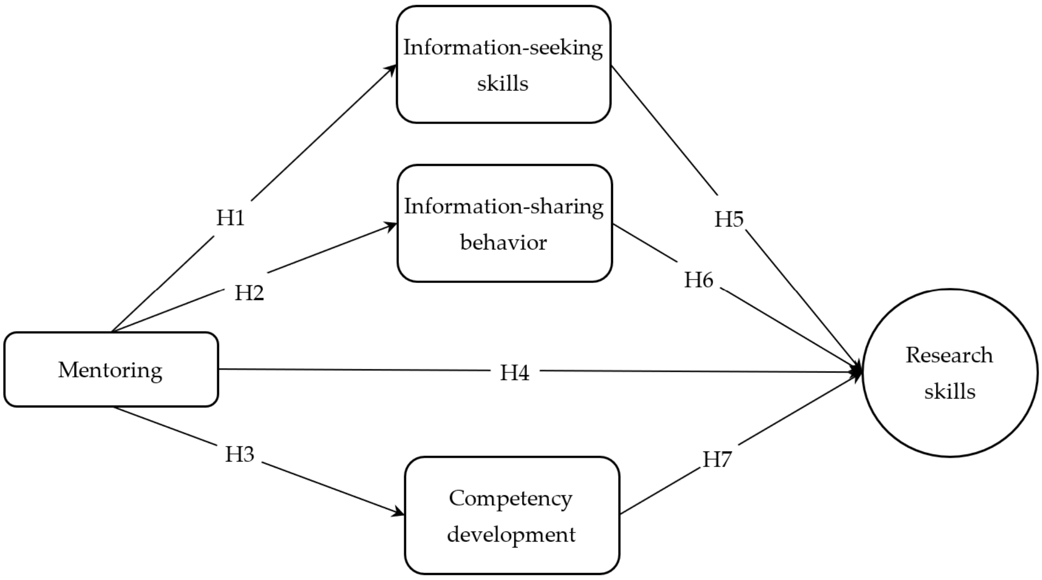

Figure 1. The proposed structural model.

3. Methods

3.1. Sampling and Data Collection

The measurement items for each construct in this work were adopted from validated measures generated from previous works, as summarized in Appendix A. Mentoring (MEN) construct has eight measurement indicators, competency development (CD) has seven measurement indicators, information-sharing behavior (ISB) construct has four measurement indicators, information-seeking skills (ISS) construct has three measurement indicators, and research skills (RS) construct has eight measurement indicators. The survey instrument was refined by academic experts, and the wording relevant to research skills was revised. Furthermore, the survey instrument measures all the constructs using a 7-point Likert scale with measurement items of all constructs ranging from 7 as "strongly agree" to 1 as "strongly disagree" and a qualifier question of "Have you taken any research course?". Also, a consent form was attached to the survey questionnaire to ensure that participants were adequately informed and gave consent to participate in the study on a voluntary basis. The consent form allows the participants to withdraw from answering the study at any time if they feel uncomfortable with the questions. This work utilized a random sampling technique. The survey instrument was translated to Google Forms for convenience, efficient administration, and cost efficiency. The survey questionnaire was personally administered by enumerators with smart devices and an internet connection and was only disseminated online for three weeks, from 3 March 2023 to 24 March 2023. The participants were undergraduate college students that have taken their research course (e.g., undergraduate thesis writing) in the Philippines. There were 610 responses collected. Thirty-seven did not provide consent to answer the survey, and thirty-four had non-engaging responses, which were eliminated from the analysis. Of the 610, only 539 were valid and used for the final analysis. There was no missing data in the survey since all questions were required to have a response.

3.2. Profile of the Participants

The majority of the undergraduate student participants had an academic major in education (26%), engineering and technology (24%), and tourism and hospitality (16%), as presented in Figure 2. In this work, the undergraduate students were identified primarily as female (73%). Since a qualifier question was incorporated in the survey questionnaire, all participants completed a research course culminating in an undergraduate thesis project. They were prompted to think about their experience during their respective research classes and the mentor they had during the implementation of their undergraduate research project. In the case of most universities in the Philippines, undergraduate students are required to form a group of three to five members drawn from the same research class. Each group is supervised by a faculty member acting as an adviser who is considered their mentor in completing an undergraduate research project, a requirement for the course. It is noteworthy that advisers or mentors of these projects possess comparable qualifications, including holding a master's degree in the discipline they mentor. Also, faculty members in most Philippine universities obtained their undergraduate and graduate qualifications from nearby universities, with an estimated ratio of 1:100 faculty members obtaining their graduate studies abroad. This scenario demonstrates the homogeneity in the professional roles and qualifications of all mentors in undergraduate research projects.

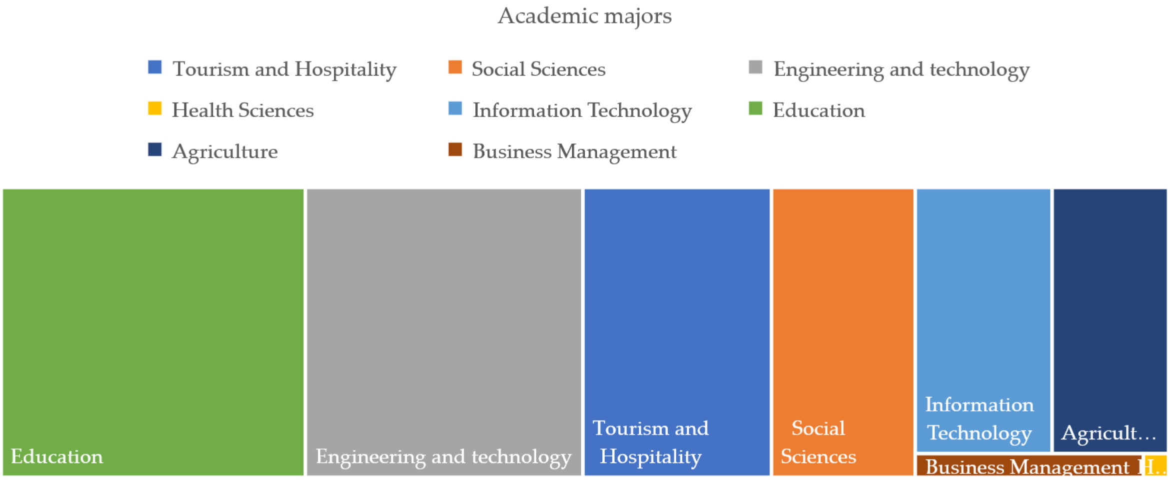

Figure 2. Academic major of the participants.

3.3. Data Analysis Results

Two structural equation modeling approaches are widely available: (1) Partial Least Squares–Structural Equation Modeling (PLS-SEM) and (2) Covariance-Based Structural Equation Modeling (CB-SEM). Specifically, PLS-SEM and CB-SEM differ in several aspects. First, in studies that aim at testing or confirming a theory, the appropriate method is CB-SEM, which focuses on the model fit, while PLS-SEM aims to maximize the covariance between latent variables for improved model interpretation [69,70]. Second, CB-SEM is restricted to reflective constructs, although some studies utilized formative measurements in the structural model leading to identification issues. In contrast, PLS-SEM can analyze research models that include both reflective and formative constructs, providing a more flexible approach [71,72]. Third, CB-SEM requires meeting assumptions related to data normality, independence, and uniformity, which can lead to inaccurate results if violated, while PLS-SEM is a more robust method for analyzing data with a non-normal distribution, using standardization techniques to align with the central limit theorem [70,73–75]. Finally, PLS-SEM can perform predictive analysis of dependent latent variables, while CB-SEM overlooks the prediction goal of empirical research [70,76]. PLS-SEM is widely recognized as the optimal analytical tool for obtaining crucial information on the antecedents or drivers of a specific construct [77]. Thus, this work utilized PLS-SEM to establish logical criteria and assess the direct relationship between the exogenous and endogenous constructs. Furthermore, as discussed, PLS-SEM is a more robust and comprehensive statistical method for determining structural models in highly complex domains [78]. In the analysis, this study used the SmartPLS software version 4.0.8.5.

4. Results

4.1. Measurement Model Assessment

The parallel testing of the outer measurement model and the inner structural model, as well as the presence of both reflective and formative latent variables, is facilitated by PLS analysis [79]. Since the proposed model in this study includes reflective measures, the first criterion in evaluating the model is to examine the validity and reliability of the measures [80]. As per the assessment of the measurement model, all indicators are convergent and reliable, as shown in Table 1. Convergent validity examines how well individual items align within a construct and assesses the correlation between items measuring the same variable [81,82]. A construct is considered to have convergent validity when its Average Variance Extracted (AVE) value is at least 0.5 [83]. However, this study accepts a factor loading of 0.65 for each item. Those with an outer loading above 0.65 are regarded as acceptable, while those with a loading value of less than 0.65 are removed [71]. No measurement indicators are removed after calculations through the SmartPLS algorithm since all indicators reach the threshold value of 0.65. All constructs have the appropriate convergent validity ranging from 0.573 to 0.724. Reliability and validity testing is conducted using composite reliability (CR) aside from the traditional Cronbach's (α). CR is preferred in PLS-SEM as it considers varying indicator loadings and avoids underestimation issues associated with Cronbach's α [77]. Furthermore, the measurement items are all reliable, with all the constructs reaching above Cronbach's alpha (α) threshold value of 0.70, which is considered a reliable and acceptable index [84,85], and the composite reliability (CR) threshold value of 0.70 [80]. The Cronbach's alpha ranges from 0.808 to 0.911, while the CR values range from 0.810 to 0.944. These results indicate high-reliability values.

Table 1. Measurement model assessment results.

	Convergent Validity		Construct Reliability			Convergent Validity		Construct Reliability	
	Loading	**AVE**	**CR**	**α**		**Loading**	**α**	**CR**	**AVE**
CD1	0.770	0.653	0.912	0.911	MEN1	0.723	0.573	0.894	0.893
CD2	0.841				MEN2	0.762			
CD3	0.852				MEN3	0.758			
CD4	0.787				MEN4	0.793			
CD5	0.792				MEN5	0.773			
CD6	0.799				MEN6	0.730			
CD7	0.813				MEN7	0.768			
ISB1	0.809	0.639	0.81	0.808	MEN8	0.746			
ISB2	0.676				RS1	0.751	0.717	0.944	0.943
ISB3	0.856				RS2	0.847			
ISB4	0.844				RS3	0.870			
ISS1	0.810	0.724	0.818	0.810	RS4	0.894			
ISS2	0.869				RS5	0.879			
ISS3	0.872				RS6	0.847			
					RS7	0.841			
					RS8	0.839			

Note: α = Cronbach's alpha; CR = composite reliability; AVE = average variance extracted; CD = competency development; ISB = information-sharing behavior; ISS = information-seeking skills; MEN = mentoring; RS = research skills.

The degree to which a construct is empirically distinct from other constructs is called discriminant validity. Fornell and Larcker's [83] criterion is a common method in assessing discriminant validity and typically reveals collinearity issues in the inner model. The AVE of the discriminant validity constructs is greater than the squared correlation of each latent variable [83]. The square roots of the AVE are bolded in Table 2, whereas non-bolded values represent the intercorrelation value between constructs. All off-diagonal values are less than the square roots of AVE, indicating that the Fornell and Larker condition is satisfied.

Table 2. Fornell and Larcker results.

	Competency Development	Information-Sharing Behavior	Information-Seeking Skills	Mentoring	Research Skills
Competency development	**0.808**				
Information-sharing behavior	0.409	**0.800**			
Information-seeking skills	0.421	0.507	**0.851**		
Mentoring	0.671	0.369	0.379	**0.757**	
Research skills	0.332	0.386	0.422	0.260	**0.847**

Note: Square root of AVE is shown on the diagonal of the matrix in bold; inter-construct correlation is shown off the diagonal.

The Standardized Root-Mean-Square Residual (SRMR) measures the average discrepancy between observed and expected correlations in a structural equation model. It provides an absolute assessment of model fit by indicating the magnitude of these discrepancies. A threshold value below 0.10 or 0.08 [86] generally indicates a good fit. Henseler et al. [87] introduced the SRMR as a useful goodness-of-fit measure in PLS-SEM, helping to identify and prevent model misspecification. In this study, the SRMR value is 0.054, lower than the threshold standard acceptable fit value of 0.08. The Normed Fit Index (NFI) is a metric used in PLS-SEM to assess the overall fit of the model to the data [88]. It compares the fit of the estimated model with that of a null or baseline model, considering the degrees of freedom. The NFI ranges from 0 to 1, with values closer to 1 indicating a better fit. It shows how accurately the model captures the observed covariances between the variables. In this work, the NFI value is 0.848, reflecting a moderate fit, an acceptable value. Thus, the research model fitness demonstrates an acceptable fit.

4.2. Structural Model Assessment

This work assesses the predictive power of the endogenous variables in the model [89]. The main criteria for evaluating the structural model using PLS-SEM are the strength of path coefficients, R^2 values (prediction power), and f^2 (effect size), as suggested by Hair et al. [80]. The coefficient of determination (R^2) measures the model's predictive accuracy. The combined influence of the exogenous variables on the endogenous variable(s) ranges from 0 to 1, with 1 corresponding to complete predictive accuracy. The acceptable R^2 of 0.75, 0.50, and 0.25 correspond, respectively, to substantial, moderate, and modest levels of prediction accuracy [72,74]. In this study, R^2 provides the predictive accuracy of the structural model, as shown in Figure 3. CD explains the highest variance with an R^2 value of 0.468 (46%). Furthermore, other constructs have a modest prediction accuracy, with RS, ISS, and ISB having R^2 of 0.255 (25%), 0.162 (16%), and 0.152 (15%), respectively. All of the hypotheses (H1, H2, H3, H5, H6, H7) are supported except for H4. These are summarized in Table 3 and visualized in Figure 3.

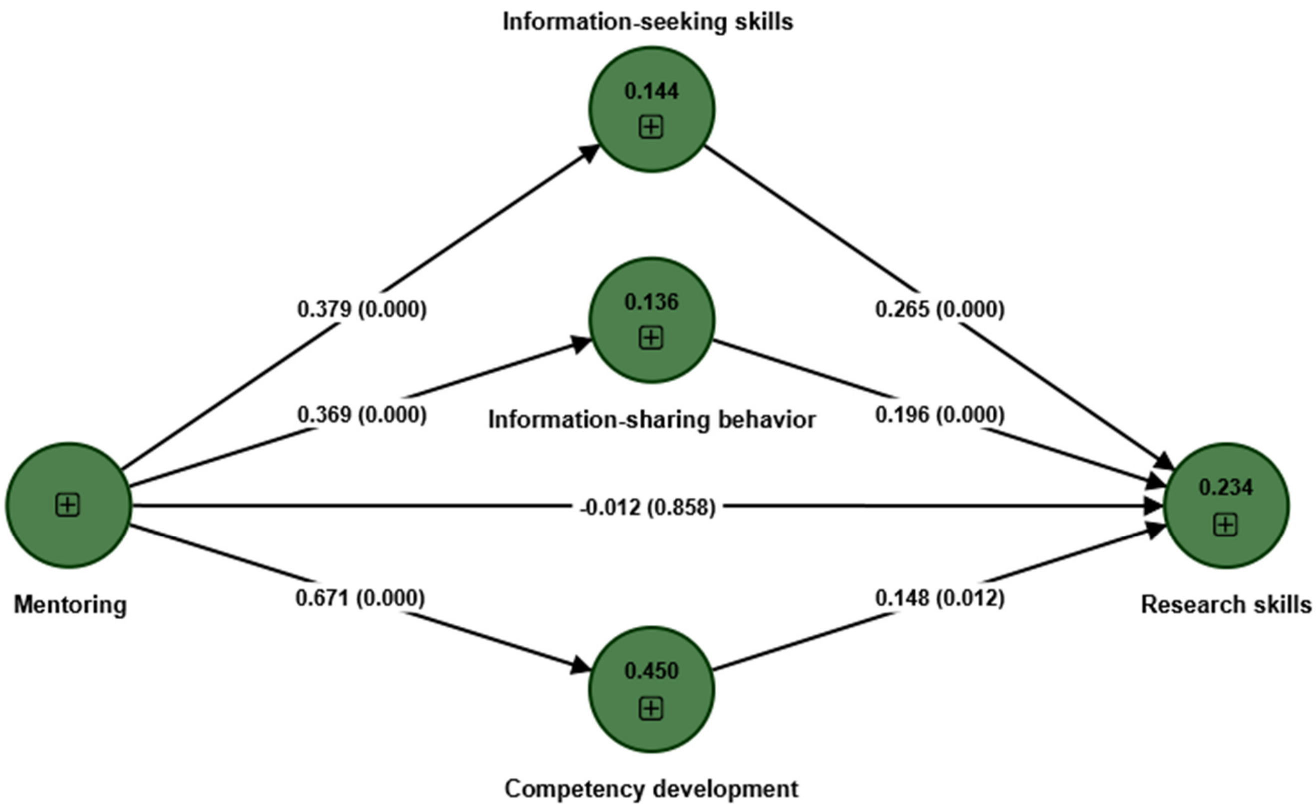

Figure 3. Structural model.

Table 3. Path coefficient results.

Hypotheses	β	t Values	*p* Values	Decision
H1: Mentoring → Information-seeking skills	0.379	8.363	0.000 ***	Supported
H2: Mentoring → Information-sharing behavior	0.369	9.672	0.000 ***	Supported
H3: Mentoring → Competency development	0.671	12.798	0.000 ***	Supported
H4: Mentoring → Research skills	−0.012	0.179	0.858 ^{ns}	Not Supported
H5: Information-seeking skills → Research skills	0.265	5.086	0.000 ***	Supported
H6: Information-sharing behavior → Research skills	0.196	3.556	0.000 ***	Supported
H7: Competency development → Research skills	0.148	2.514	0.012 **	Supported

Note: *** $p < 0.000$; ** $p < 0.001$; ns not significant.

The effect size, as defined by Cohen [90], Cohen [91], and Kock [92], represents the magnitude of an effect irrespective of the sample size being examined. Using the PLS algorithm, the effect size (f^2) values are estimated, indicating 0.02 (minor), 0.15 (medium), and 0.35 (substantial) effects on the relationship between exogenous and endogenous constructs [80]. Furthermore, a value less than 0.02 implies no effect of exogenous constructs on an endogenous construct. In this study, the f^2 results show that MEN has a substantial effect on CD (f^2 = 0.818). Moreover, MEN has a medium effect on ISB (f^2 = 0.158) and ISS (f^2 = 0.168). Both ISB and ISS have a medium effect on RS with (f^2 = 0.035) and (f^2 = 0.062), respectively. However, CD has a negligible effect on RS (f^2 = 0.014), and MEN has no effect on RS (f^2 = 0.000). These results are consistent with the other findings of the study.

4.3. Mediating Effect

The mediating relationships in the structural model are shown in Figure 3. In this work, the mediator analysis procedure in the PLS of Zhao et al. [93] is followed as Hair et al. [94] suggested for PLS-SEM. The result shows that information-seeking skills, information-sharing behavior, and competency development fully mediate mentoring to students' research skills since H4 is not supported.

5. Discussion and Insights

Drawn from Bandura's social learning theory, this study examines the proposed structural model that highlights how undergraduate students' research skills are improved by mentoring initiatives of faculty researchers in an academic institution. In addition, it investigates the mediating roles of information-seeking skills, information-sharing behavior, and competency development in the relationship between mentoring and research skills. The proposed structural model finds its motivation from existing studies emphasizing the role of mentoring in offering guidance, support, and feedback to students along the research process [20,22]. Due to the compelling factors associated with mentoring, as espoused by Malcom and Feder [51], information literacy and competency development constructs are hypothesized to mediate the direct relationship between mentoring and research skills. Such an attempt reflects the components of social learning theory, which suggest that behaviors of individuals are not only shaped through observational learning (i.e., mentoring or role modeling) but also require cognitive processes that they deem to perform and the need for reciprocal determinism and feedback mechanisms. The limited insights in the domain literature require empirical evidence to support the design of initiatives to improve undergraduate students' research skills. Seven hypothesized paths are examined. The cross-sectional empirical analysis demonstrated in this work supports six of the seven hypotheses, leaving the direct path from mentoring to research skills unsupported.

The findings show that mentoring enhances the information-seeking skills of undergraduate students (H1), supporting the findings of Ransdell et al. [20]. An important component in the completion of the undergraduate research project, particularly in its initial phase (e.g., review of the extant literature), is the guidance of the mentor on how to search for references effectively (e.g., journal articles, conference papers, books) to build up the background of the project. This includes a critical understanding of the available platforms to search for these references, the quality of information present, and the amount of information necessary to build up the arguments that serve as the groundwork for the project. Over time, in a constant one-on-one interaction between the faculty mentor and student mentees, such skills are refined, the behavior is developed, and the seeking of information becomes more efficient. This view supports the social learning theory in a more straightforward manner in such a way that the information-seeking skills of mentees are driven by observational learning from their mentors. This relationship extends to the information-sharing behavior of students, supporting H2. With mentors possessing higher digital literacy for efficient collaboration and information sharing among peers via online platforms, the mentoring initiative facilitates knowledge transfer to students. Particularly in an undergraduate research project that comprises two or more students as member proponents, student mentees would find it more beneficial to gain those information-sharing skills from their mentors, such as the use of cloud storage and real-time collaboration platforms (e.g., Google Docs, Microsoft Teams, Slack, Asana, Trello, Zoom, Figma, Miro). With more relevance during the COVID-19 lockdowns, such tools have become imperative to support efficient communication among project members. Thus, as the study findings suggest, mentoring promotes undergraduate students' information literacy.

The role of mentoring in espousing competency development is also empirically supported in this study (H3). The most straightforward tasks of good mentors are ensuring that student mentees receive sufficient guidance, develop critical thinking, enhance their knowledge base of the discipline, receive helpful feedback, and promote creativity. These initiatives improve the necessary competencies pivotal in completing the research project. Since student mentees look up to mentors as role models, these competencies are honed during the mentoring process until the student's potential eclipses their mentors'. This finding also supports the core concept of observational learning and role modeling that the social learning theory describes in shaping behaviors and skills. On the other hand, the hypothesized relationship between the information-seeking behavior and research skills (H5) of students is supported in this study. Those skills that can identify sources of information, evaluate the quality of information from these sources, and utilize this information to draw arguments augment several aspects of undergraduate research project implementation. These include (1) the use of bibliographic records; (2) the formulation of a scientific problem, research objectives, and research hypotheses; (3) the selection of the population, the sample, and appropriate type of sampling; (4) the selection, development, and application of methods, techniques, and instruments; and (5) the analysis and processing of information. Students who lack the behavior of seeking, organizing, and utilizing information would find it difficult to execute these aspects in the research process. Hence, a straightforward role of information-seeking behavior is deemed apparent in developing research skills. Our finding also suggests that the information-sharing behavior of students develops their research skills (H6). A plausible view of this relationship is the two-way effect that students experience during information sharing. When students share critical information they know, they always get feedback from their peers and even outside the institution. The feedback loop helps refine their knowledge, correct knowledge gaps, and eventually enhance the existing information they possess. The continuous feedback during information sharing promotes those research skills (i.e., searching for relevant sources, formulating the research questions, selecting the appropriate methodology, properly applying the methods, and analyzing the findings), interpreting the results, drawing conclusions, and writing the final report. On the other hand, the competency development of students also promotes their research skills (H7). Such a relationship is almost straightforward. Students who develop the competencies necessary for implementing research projects demonstrate their research skills more efficiently and effectively. These competencies form the baseline for students to carry out the skills needed to complete their projects. The findings of H5, H6, and H7 can be explained from the lens of social learning theory in the following manner. The presence of information literacy and competency development of undergraduate students reinforces their self-efficacy, which is a central concept in Bandura's social learning theory. As students gain knowledge (i.e., through information seeking and information sharing), skills, and competencies in carrying out a research project, their belief in their own abilities increases.

Finally, the most critical finding of this study is the unsupported relationship between mentoring and research skills (H5). This suggests that mentoring does not directly translate to developing the research skills of students, at least in carrying out their undergraduate research projects. In effect, mentoring can only develop those skills if students possess information-seeking skills and information-sharing behaviors and develop their required competencies, as implied in the full mediating roles of their constructs. This finding offers important insights. First, those role-modeling demonstrations in the form of sharing the history of the mentor's career, revealing personal experiences, and conveying respect have an insignificant impact on molding students' research skills. This implies that abstract motivational sharing could hardly translate to the actual development of students' research skills unless they enhance students' behaviors to seek and share information and promote competency development. Secondly, while mentoring allows the mentor to recommend specific strategies to accomplish the project and help finish certain assigned research tasks, without the information literacy and developed competence of students, it does not improve their research skills. This may be viewed as follows. For instance, the mentor may direct a student to implement a specific modeling methodology to analyze the causal relationships between variables in a research project. While such directives may complete the tasks at hand, when students' creativity to seek and share information and students' effort to consciously perform abstraction about the tasks to improve their competence are missing, they cannot replicate the use of such a methodology to understand another differently framed research question. Thus, mentors must not only focus on directing the mechanical aspects of doing the tasks associated with the method; instead, they must put emphasis on shaping students' behaviors to think and figure out why such a method is necessary for a given problem and how to manipulate and extend the same method to address future research questions. Such behaviors demand greater information literacy and competence development. Third, while students receive opportunities to learn new skills during the mentoring process, these skills must be paired with the conscious effort to distill, interpret, and utilize information to translate those opportunities into developed research skills. These insights associated with the full mediation of information literacy and competence development between mentoring and research skills are deemed novel in the literature.

Furthermore, the insights of our empirical study espouse the social learning theory of Bandura [42] in the following areas. First, role modeling and mentoring (i.e., observational learning) shape certain skills that may require less sophistication, such as increasing information literacy and competency development. Information-seeking skills can be directly shaped by observational learning as the process of information seeking can be thought of as highly mechanical and procedural than cognitive. Similarly, individuals develop some aspects of competencies from their mentors as part of observational learning. Meanwhile, one aspect of mentoring forms reinforcement through rewards and punishments that individuals (or students) receive from their mentors, which enables them to imitate and perform those skills being rewarded. Also, the exchange process of sharing information among peers, as in the case of members in a project, supports one of the fundamental aspects of social learning theory known as reciprocal determinism [42]. It suggests that individuals do not only learn from their environment, but they also actively influence their environment through the information they learn from various sources, facilitating the social aspect of the theory. Second, in relation to the first, observational learning may not shape highly sophisticated skills. Like other complex skills, research skills require more dynamic cognitive skills that can distill, synthesize, and combine concepts in a creative fashion and are adaptive to changes in several factors related to study design, data and information processing, weather conditions, policy-driven nuances, and other environmental factors. Thus, characterizing specific skills primarily driven by observational learning becomes imperative. Third, enforcing self-efficacy in individuals to perform sophisticated skills can be highlighted as a direct implication of the full mediation effects of information literacy and competency development between mentoring and research skills. Emphasized as fundamental in social learning theory, self-efficacy influences whether an individual performs or imitates a specific skill or behavior. In our empirical work, observational learning through mentoring promotes information literacy and competency development, eventually enhancing self-efficacy. Increasing self-efficacy for highly sophisticated skills, such as carrying out research projects, is critical for augmenting those skills. Thus, observational learning and role modeling must be designed to increase self-efficacy in complex tasks.

6. Concluding Remarks

6.1. Summary

This work proposes and validates an empirical model motivated by the social learning theory that explains the development of research skills of undergraduate students. Due to the multiple stages associated with undergraduate research projects, mentoring between faculty researchers and students within the same or different institutions becomes apparent. While the current literature offers empirical support linking mentoring and general research skills, specifically exploring undergraduate students' research skills is limited. Such an agenda may not be straightforward, as these students typically face research tasks for the first time. Thus, the proposed structural model espouses the possible mediating role of information-seeking skills, information-sharing behavior, and competency development in the relationship between mentoring and research skills. The model proposes seven hypothesized paths, and 539 valid participants are used to test these paths via PLS-SEM. All hypotheses are supported, except for the direct link between mentoring and research skills, implying that information literacy constructs and the competency development of students fully mediate such a relationship.

6.2. Implications

The findings of this study show three critical contributions. First, mentoring positively supports information-seeking skills, information-sharing behaviors, and competency development, partially supporting others in the literature. This implies that the technical guidance of the mentor on continuous one-on-one interaction with the student mentee refines the student's behavior in critically seeking information, assessing its quality, and creatively utilizing such information to build arguments for the research project, contest theories, and identify appropriate methodologies. On a similar note, mentors possessing high digital skills can transfer knowledge to students by sharing information to achieve collective success for the project, especially for undergraduate students who typically work in teams. The path from mentoring to competency development offers direct evidence regarding how mentors shape the required competencies of students to carry out research tasks. Secondly, the paths from information literacy and competency development constructs to research skills are positively supported in this study. This finding suggests that students who seek information and share it with peers or team members improve their research skills in accessing relevant sources, establishing research questions, evaluating appropriate methods, implementing those methods, interpreting findings, drawing relevant conclusions, and writing reports. In particular, the feedback loops in information sharing promote the development of the required research skills in completing projects. Finally, our findings demonstrate the full mediation effects of information literacy constructs and competency development, opposing the direct link of mentoring to research skills. This novel empirical support highlights the need for mentors to shape students' information-seeking and information-sharing behaviors to effectively translate mentoring efforts to developing hard research skills. They must focus beyond the mechanical aspects of performing the tasks to espousing students' creativity to consciously perform abstractions to address future research questions that may be framed differently. Such an initiative requires students to develop information-seeking and sharing behaviors, along with training that enhances their competencies.

6.3. Limitations and Future Work

Although these findings are pivotal in the literature, some limitations are evident. First, the participants in this study are from the Philippines, with inherent cultural and political makeups. Future work may expand our empirical model to a multi-cultural investigation with more participants. A multi-group analysis in PLS-SEM may identify the differences brought about by these varying cultural biases. Secondly, the participants belong to institutions with heterogeneous academic reputations. Some of them came from top-ranked universities with excellent faculty resources. In effect, the quality of the mentorship programs present in these universities may be significantly different from those in the lower-ranking quartiles. Thus, future studies may look into the technical competence of mentors as a moderating variable in developing research skills. Finally, predictive machine learning algorithms based on several factors leading to improving research skills may be interesting for future work.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data will be made available upon request.

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

Appendix A

Table A1. Measurement indicators.

Constructs	Indicators	References
Mentoring (MEN)	MEN1. My mentor shares the history of his/her career with me. MEN2. My mentor discusses my questions regarding feelings of competence and commitment to advancement. MEN3. My mentor shares personal experiences as an alternative perspective on my problems. MEN4. My mentor suggests specific strategies for accomplishing work objectives. MEN5. My mentor gives me assignments that present opportunities to learn new skills. MEN6. My mentor helps me to finish assignments. MEN7. My mentor conveys feelings of respect for me as an individual. MEN8. I respect and admire my mentor.	Younas and Bari [95]
Competency development (CD)	CD1. A more experienced mentor who guides me in my research and from whose experience I can learn. CD2. My adviser ensures I learn about the research by giving me challenging assignments. CD3. My adviser makes sure that I develop the competencies that I need for my research career. CD4. In my organization, training sessions are organized to gain knowledge. CD5. My adviser regularly gives me feedback about my performance. CD6. I can make use of personal development plans to know what competencies I need to develop. CD7. I have been given tasks that develop my competencies for the future.	Younas and Bari [95]

Table A1. *Cont.*

Constructs	Indicators	References
Information-seeking skills (ISS)	ISS1. I can use a variety of available options to search for information that my colleagues are not aware of. 1SS2. I can inform my classmates of different ways to effectively search for information. 1SS3. I can generate keywords to search for information for academic work.	Hong and Kim [96]
Information-sharing behavior (ISB)	ISB1. I can interact with classmates using real-time communication tools, for example, video conferencing tools or messengers. ISB2. I can share my opinions online, for example, with blogs, social networking services, or web pages. ISB3. I can share my files with classmates using online software. ISB4. I can collaborate with classmates using online software.	Hong and Kim [96]
Research skills (RS)	RS1. Use of catalogs, descriptor books and bibliographic records. RS2. Relation to the formulation of a scientific problem, research objectives, and research hypotheses. RS3. Selection of the population, the sample, and the type of sampling to be used. RS4. Selection, development, and application of methods, techniques, and instruments. RS5. Analysis and processing of information through different statistical techniques. RS6. Interpretation and discussion of results are presented in tables and graphs. RS7. Drawing up conclusions and recommendations. RS8. Writing final research reports.	Ipanaqué-Zapata et al. [97]

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education sciences

Article

Health and Well-Being in Higher Education: Student Perception of an Australian University

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Abstract: The health and well-being of university students is a priority agenda, given the need to advance health in the university system and the United Nations Sustainability Development Goal regarding quality and inclusive education. However, current literature lacks adequate insights regarding health and well-being considerations. This study investigated students' perceptions concerning how university students experience health and well-being. The study is underpinned using the biopsychosocial model of health and was conducted via a cross-sectional student survey with quantitative and open-ended questions at an Australian university in 2021. A hierarchical regression model with 625 respondents indicated health and well-being are significantly influenced by mental (t-value = 15.7, $p < 0.001$), physical (t-value = 9.48, $p < 0.001$), university learning (t-value = 5.16, $p < 0.001$), and economic (t-value = 4.78, $p < 0.001$) domains regardless of the demographic and study characteristics of students. Students' perception of their health and well-being varied according to student age, the college of study, and whether they were an international student. Both the quantitative and qualitative findings supported that the mental, physical, university learning, and economic domains of students' health and well-being are interdependent. There is a case for a proactive, continuous, inclusive, and holistic health and well-being approach to support student success in higher education.

Keywords: biopsychosocial model of health; university student; well-being; psychological well-being; university learning; economic well-being; physical; mental; social

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1. Introduction

Pressure to achieve a high level of academic performance, manage the study load of fast-track courses or remote learning, and negotiate the cultural differences among peers, often being distant from family support, and transition to independent decision-making for the first time in their lives are just a few examples of difficulties higher education students are facing [1–4]. Student health and well-being is also a relevant agenda in the United Nation's Sustainable Development Goals (UN SDGs) to sustain quality and inclusive education (SDG 4) and development of the community (SDG 3, 10, 11, and 17) [5]. Reflecting on the significance of the agenda, ongoing research on the complexities of health and well-being of higher education students is noted globally, across countries such as the United States of America (USA), China, Australia, Canada, United Kingdom (UK), Belgium, Thailand, and India [1,6,7].

Despite the considerable momentum in the well-being literature, our understanding of the health and well-being experience of higher education students is limited. Often, universities conduct student engagement and experience surveys [8] that do not provide a comprehensive assessment of health and well-being issues. Furthermore, the literature regarding health and well-being is skewed towards the mental and physical aspects, lacking consideration of additional educational, economic, and social aspects of well-being [6]. There are only a few exceptional practices, for example, the Canadian Campus Well-being Survey (CCWS) that assesses student well-being beyond the mental and physical aspects [9].

Conceptualisation and assessment of the health and well-being of students needs to be a regular exercise, given that the concept can evolve with continuing changes in higher education [10]. In developed countries, in line with the ethos of sustainable development goals, universities are continuing to advance health in the university system and helping students with community connectedness [11]. Initiatives to facilitate student success, that is, positive outcomes for students, such as academic learning, retention, and enhanced well-being, are being implemented to provide positive structural and psychosocial assistance for diverse cohorts of students [2,12,13]. Furthermore, the recent experience of the COVID-19 pandemic has exposed students to unprecedented levels of economic, psychological, and social adversities [14–16], highlighting how universities should be adaptive in their teaching pedagogy and student well-being arrangements [13].

There are a range of understandings of 'health' that are foundational to the conceptualisation of students' health and well-being. These interpretations of health are underpinned by disciplines involving biological, economic, environmental, political, psychological, and sociological ways of constructing meaning [17]. In recent decades, 'health' has become more holistically positioned, extending the focus from a traditional biomedical understanding in which the physical body is dominant [18]. The UN SDGs [5] recognise health and well-being as one broad concept, in line with the wide-ranging literature that perceives health as a multidimensional and dynamic phenomenon [19,20]. The phenomenon is expected to be influenced by social structures, including housing, education, socioeconomic status, age, gender, transport, and social support [17].

Considering the significance of the health and well-being agenda and the evolving state of higher education, this study examines the research question "How do university students experience health and well-being?". This study has conceptualised health and well-being, in line with literature on the biopsychosocial model of health [19–21]. The study context is a public university in Australia that has experienced the changing scene of higher education as explained above. The study can offer transferable insights to conceptualise health and well-being for higher education systems around the world. Moreover, the study intends to provide insights for universities to advance student success with a holistic approach and integrated solutions for students' health and well-being.

2. Theoretical Background

The biopsychosocial model of health [19–21] provides a holistic approach to health and well-being that is necessary for higher education students. The task involves not only understanding the mental and physical state of students but also other factors relevant to students' university journey. The biopsychosocial model divides health into a biological aspect, for example, the biological functioning of the body and its organs; a psychological aspect, for example, the subjective mental health experience; and finally, a social aspect, for example, the interpersonal experiences that operate between individuals, family, and community [19]. According to this model, this study has the premise of equal importance of biological, psychological, and social aspects in defining the health and well-being of higher education students [20]. The other premise of the study, underpinned by the biopsychosocial model and literature on student well-being, is that biological, psychological, and social aspects of health and well-being are interdependent, to the extent that the three aspects can influence each other and change the original state of an aspect [22]. The following sections apply the biopsychosocial model to identify certain dominant domains of student well-being in higher education, for example, mental, physical, university learning, and economic.

Mental well-being reflects the subjective mental state of students [23,24]. The rationale of this domain is founded on the psychological aspect of the biopsychosocial model, which evidences a positive mental state, for example, when student satisfaction contributes to the well-being of school students [25]. Physical well-being sits in the biological aspect of the biopsychosocial model and portrays a student's biological state of the presence or absence of physical discomfort [19,25]. It is expected that a student who suffers less from physical discomforts and has an active physical lifestyle will enjoy better satisfaction and positive subjective well-being in life [26,27].

The social aspect of the biopsychosocial model hosts the domain of university learning well-being. This domain is justified by the notion that the quality of life of a student is dependent on how well supported they are by the education system and social interactions at the university [26]. Further support for this domain is the evidence of how a student's social interaction with fellow students contributes to positive engagement in university learning [28]. The final domain, economic well-being, mainly falls into the social aspect of the biopsychosocial model. The domain is supported by the notion that economic resources, for example, financial security for food, accommodation, and digital resources, are crucial to accessing an improved lifestyle and education in the community [26,27].

3. Materials and Methods

3.1. Setting

The setting of this study, a long-established higher education institute, consists of three main campuses, with four small and specialised satellite facilities. The university offers several disciplines of undergraduate and postgraduate coursework programs across six colleges and research courses. Currently, close to 25,000 national and 7000 international students from 147 countries are studying at this university in a variety of fee-paying structures, for example, scholarships and student loans. The university has a five-year strategic plan in place, addressing goals aligned with the UN SDGs.

3.2. Sample Selection and Survey Procedure

The study applied a cross-sectional survey, within a convergent parallel mixed-methods research design [29]. Participants were enrolled university students at any of the campuses at the selected university for a minimum of 18 months. The university survey team invited all eligible students to take part in an online, voluntary, and anonymous survey that took place in April 2021. The inclusion criteria ensured participants were exposed to health and well-being experiences both in the pre- and post-COVID-19 university environment. Prior to the survey in April 2021, one-to-one interviews with seven students were conducted to test face validity of the self-constructed health and well-being experience survey instrument. Approval for the study was given by the University's Ethics Committee (Project ID 24186).

3.3. Survey Instrument

To the knowledge of the authors, a validated survey instrument for health and well-being of higher education students that is embedded in the biopsychosocial model of health [19–21] does not exist. Accordingly, this study has merged relevant tools from the literatures and arrived at a survey instrument with eight sections. The first two sections captured student socio-demographics, for example, age, gender, parents' education, and study characteristics, for example, mode of study (face-to-face, online, or blended), type of study (part-time or full-time study) and study status (international or local student).

The next five sections of the instrument captured quantitative data for overall student health and well-being (the outcome variable) and independent well-being domains of: mental well-being, which had five questions of WHO-5 [23,24]; physical well-being, which had six questions [25]; university learning well-being, which had nine questions [9,25,27]; and economic well-being, which had six questions [9,25,27]. The overall health and well-being section had five questions [27]: one question each to summarise the overall opinion of the four independent well-being domains, plus a single-item life satisfaction question.

Students' socio-demographic and study characteristics were coded on a nominal scale. For example, gender was coded as "1" for females and "2" for males. The questions on the independent well-being domains of physical, university learning, and economic, and overall opinion of each domain were rated on a scale of 1 to 5, with 1 = strongly dissatisfied, 3 = neutral, and 5 = strongly satisfied. An exception was the question about students' life satisfaction in overall health and well-being (the outcome variable), which had a scale of 0 to 10, with 0 = extremely dissatisfied, 5 = neutral, and 10 = extremely satisfied [27]. Also, the questions on mental well-being were rated on a scale of 0 to 5, with 0 = at no time, 2 = less than half the time, and 5 = all the time [23,24]. Lastly, the survey covered an open-ended question for qualitative comments on well-being issues (physical, economic, mental, university learning, or COVID-19-related) experienced as a student.

3.4. Quantitative Analysis

The survey data were screened for missing data, finding that certain responses had about 20% missing data. To adjust for the missing data, in each data analysis in SPSS (Version 28), a respondent's data were included only if a complete set of data for the relevant analysis was available. Hence, there was variation in the number of respondents applicable for different analyses. Overall, three major analyses of data were conducted in this study. First, the internal consistency of each of the four independent domains of well-being (mental, physical, university learning, economic,) was analysed with Cronbach's alpha (CA). Second, analysis of mean and percentage, and a two-tailed Pearson correlation, were conducted to identify the areas of improvement in the health and well-being experience of students.

Third, hierarchical multiple regression was run to assess the association between the four predictive/independent well-being domains (mental, physical, university learning and economic) and the outcome variable "overall health and well-being". While running the hierarchical regression in SPSS (Version 28), the usual options such as "collinearity diagnostic", "casewise diagnostics" were chosen; for outliers outside 3 standard deviations, "standardised residual normal probability plot" and Cook's distance check were chosen. Moreover, the outcome variable "overall health and well-being" was tested for normal distribution through the "Explore" option in SPSS (Version 28).

In this hierarchical regression, predictive variables were entered in the model in two blocks. The first block entered the eight socio-demographic and study-related control variables, such as age and online/face-to-face study, as shown in Model 1 in Table 1. The second block entered the four independent domains of well-being as shown in Model 2 in Table 1. The movement of adjusted R2 and F values between models 1 and 2 clarified whether the four independent well-being domains explained the overall health and well-being experience of students, despite students' socio-demographic and study characteristics.

Table 1. Predicting factors of students' overall health and well-being experience.

	Model 1			Model 2		
Factors	**Coeff. Standard Error**	**Standardized Coeff. B**	**t-Value**	**Coeff. Standard Error**	**Standardized Coeff. B**	**t-Value**
Constant	0.4	-	**8.15** ***	0.28	-	0.60
Age	0.03	0.16	**3.27** ***	0.02	0.17	**2.35** **
Gender	0.09	0.04	1.04	0.05	−0.03	−1.31
Domestic/International	0.14	0.04	0.78	0.08	−0.01	0.78
University-educated parent	0.04	0.11	2.6	0.03	0.03	1.95
Residing in Australia	0.24	−0.04	−1.01	0.14	0.02	0.90
Online/Face-to-face study	0.04	0.03	0.75	0.02	0.03	1.13
College of Study	0.03	0.01	0.21	0.02	0.05	**1.9** *
Part-time/Full-time study	0.10	−0.05	−0.99	0.06	0.03	1.03

Table 1. *Cont.*

	Model 1			Model 2		
Factors	**Coeff. Standard Error**	**Standardized Coeff. B**	**t-Value**	**Coeff. Standard Error**	**Standardized Coeff. B**	**t-Value**
Mental Well-being	-	-	-	0.03	0.50	**15.74** ***
Physical Well-being	-	-	-	0.37	0.31	**9.48** ***
University Learning Well-being	-	-	-	0.03	0.12	**5.163** ***
Economic Well-being	-	-	-	0.03	0.12	**4.78** ***
R^2; Adjusted R^2	4%, 3%	-	-	66%, 66%	-	-
F (Degree of Freedom)	617 (8)	-	-	613 (12)	-	-

Note: *** Value is significant at $p < 0.001$; ** Value is significant at $p < 0.01$; * Value is significant at $p < 0.05$.

3.5. Qualitative Analysis

Thematic analysis of the student responses to the open-ended question about comments on health and well-being issues was conducted using the Nvivo 12 software program, following the method described by [30]. This approach first identified the basic themes in the responses. Then, the identified themes were further analysed using the lens of the biopsychosocial model of health. Following this second step, interim themes were organised into the domains of mental, physical, university learning, and economic well-being. In our final step of the analysis, global themes emerged which recognised the interrelationship between students' university learning and other domains of well-being.

4. Results

The study sample consisted of 871 student respondents, reflecting an 8% response rate from 11,000 students who had received the survey.

4.1. The Student Profile

Survey respondents came from across the colleges at the university (n = 851): College of Arts, Law, and Education (28%), College of Health and Medicine (28%), Research Division (20%), College of Science and Engineering (13%), and College of Business and Economics and others (11%). About 63% (n = 798) of students were studying full-time. Out of the online delivery, 15% of the cohort had temporarily shifted from face-to-face due to the COVID-19 pandemic. Domestic students covered 86% of the respondents. By demography, the cohort was female-dominant (69%, n = 850), lived in Australia (96%, n = 827), and belonged to a family with university-educated parent/s (56%, n = 669). Students belonged to different age groups (n = 851): aged below 20 to 24 (33%), aged between 25 to 34 (23%), and aged between 35 to 40 and up (44%). The demographic distribution of the respondents by age and gender was reflective of that of the overall university student population.

4.2. Health and Well-Being of Higher-Education Students

4.2.1. Quantitative Results

The outcome variable "overall health and well-being" had a non-significant Shapiro–Wilk p-value, reflecting acceptable distribution to support the multiple regression analysis. All other statistics such as the minimum (−2.5) and maximum (2) value of the standard residual and the tolerance for collinearity statistic (in the range of 0.9) were also acceptable. The four independent domains of well-being were found to be internally consistent, with a CA score of 0.89 for mental well-being, 0.83 for physical well-being, 0.70 for university learning well-being, and 0.71 for economic well-being. The results of hierarchical regression (see Table 1) evidence the four domains (i.e., mental, physical, university learning, and economic) as significant predictors of a student's overall health and well-being experience. The Model 1 data clarified that the demographic and study characteristics explained 3% of the variance in the student's overall health and well-being. In Model 2, as the four domains of well-being were added, the explanation of variance in overall health and well-being reached 66%. Hence, the inclusion of the four domains could explain an additional 63% of the variance in students' health and well-being. the influences of all the four independent well-being domains were positive, with the most and least influential domains being the mental (t-value =15.7, p = 0.000) and economic well-being (t-value =4.8, p = 0.000), respectively. A student's overall health and well-being experience positively varied with age (t-value = 2.4, p = 0.01), implying the older the student, the better the experience.

As shown in Table 2, mental well-being was the only domain that scored below the midpoint on a scale of 1 to 5. This can be a matter of concern, particularly, as mental well-being is significantly associated with students' experience of physical, university learning, and economic well-being (See Table 2).

Table 2. Descriptive analysis of the domains of students' health and well-being.

Health and Well-Being Domains	Mean (sd)	Mental WB	Physical WB	University Learning WB	Economic WB
Mental WB	2.4 (1.1)	1	**0.66** **	**0.15** **	**0.22** **
Physical WB	3.1 (0.8)	**0.66** **	1	0.10 **	**0.30** **
University Learning WB	3.5 (0.7)	**0.15** **	**0.10** **	1	0.00
Economic WB	3.9 (0.8)	**0.22** **	**0.30** **	0.00	1

Note: ** Value is significant at $p < 0.01$.

In Table 3, the two items that scored the lowest mean values in each of the well-being domains are analysed with mean value and a percentage breakdown. It is noted that improvement in well-being domains is needed across the board, regarding basic lifestyle, accommodation, the balance of face-to-face and online learning, and health and well-being support at university.

Table 3. Lowest mean scores in the domains of health and well-being (WB).

Health and Well-Being Domains	Survey Question	Lowest Score Bracket	Mean (sd)	%
Mental	I woke up feeling fresh and rested	At no time or Some of the time	1.9 (1.4)	46%
	I have felt active and rigorous	At no time or Some of the time	2.2 (1.4)	34%
Physical	I am satisfied with the way I look	Extremely or Slightly Dissatisfied	3.1 (1.2)	35%
	I am satisfied with my hours of sleep per night	Extremely or Slightly Dissatisfied	3.1 (1.3)	40%
University Learning	I am satisfied with the balance between hours of face-to-face and online learning in units	Extremely or Slightly Dissatisfied	3.1 (1.3)	34%
	I am satisfied with the health and well-being support available at the University	Extremely or Slightly Dissatisfied	3.2 (1.0)	18%
Economic	Overcrowding in my accommodation did not disrupt my studies	Never or only 30% of time	2.7 (1.8)	39%
	I did not suffer from unhealthy living conditions (e.g., damp, mold, lack of basic facilities, in need of major repairs, etc.)	Never or only 30% of time	3.0 (1.9)	49%

4.2.2. Qualitative Findings

The following section presents the three global themes drawn from the 53 pages of student responses to the open-ended survey question, which was made up of 231 individual comments. As explained below, these three themes note an interdependency between the domains.

- Mental and University learning well-being

The students recognised that mental health was at times supported by their university learning experiences. One postgraduate student explained:

> 'I always feel very supported by my supervisors at the university. My supervisors are mindful and supportive of my learning experience as a student and always check in with me to make sure everything is going well'.

However, in parallel to the above experience, it was common for students to find the university experience difficult in terms of the effect on relationships with peers and mental well-being. As the following statement indicated:

> 'Mentally, the feeling of isolation has really gotten to me lately. Though I try come into campus library as much as I can, peer interaction is minimal to none. It is extremely saddening to think I moved to ... from ... only to experience such isolation even on campus. More needs to be done to lift campus life'.

Students who had close friends were better placed in terms of the shift to online learning during the pandemic. As one student stated:

> 'My mental health is massively impacted by my experience at university. I am lucky enough to have made close friends in my first couple years of university, but without their support my current experience of online learning would be really badly impacting my mental state'.

International students at times felt lonely and unsupported, as one stated: 'I am an international student and have not been able to go home for 18 months because of COVID-19. I terribly miss home and family'. Another international spoke of racist experiences and being afraid to go out, stating, 'My girlfriend sometimes is afraid of going out since some random people would literally yell at us or flip their fingers in our faces'.

Students were aware of existing student services designed to help with mental health issues. However, they did not always find them welcoming and easy to navigate, stating:

> 'Although I am aware of services available to assist students with difficulties including mental health issues... I found these services were not terribly easy to access, particularly as someone who struggles to reach out and ask for help in the first place. I made initial online contact with support services a couple of times in the past two years or so, but I didn't follow it up any further. I wish someone might have followed up with me, given my initial outreach'.

- Physical and University learning well-being

Students also outlined how their studies at university, particularly, the remote 'online' experience, were linked to a perceived decline in their physical or bodily well-being. Sleep issues were identified, with one student explaining:

> 'It has been really difficult to stay focused and alert during online classes taken from home... tiredness makes the online classes far more difficult than face-to-face classes'.

Another stated,

> 'It has been extremely taxing on my body to study online all day. Headaches, eye twitching, back and neck pains are all products of spending too much time on a computer screen'.

Some positive health experiences were also articulated. One student suggested:

> 'My university studies have contributed to my stability, both mentally and all-round health, as I find it rewarding to be learning. I also give myself time-out from study to exercise or walk my dogs, which helps me to clear my head, relieve stress and allows reflection of ideas for assessments'.

- Economic and University learning well-being

The financial implications of university life in terms of funding the experience, accessing nutritious food, and affording suitable accommodation were important factors for a few students. One student explained:

> 'I have found it extremely difficult at times to make ends meet, to be able to afford quality food and accommodation to the point that I have been homeless and free camping for the past few months. Part time work has been very difficult to obtain due to my age. Centrelink (social security) payments are simply not enough to survive'.

Another student described the effect of financial hardship on their studies, stating: 'It is hard to focus on university studies when living at student accommodation is so expensive. It goes up each year, yet the facilities stay only adequate'.

5. Discussion

This study has explored the experience of health and well-being in higher education from the perspective of students, using the lens of the biopsychosocial model of health [19]. The study found that students' experience at university is shaped by the interrelated domains of mental, physical, university learning, and economic well-being. A variation in the level of health and well-being among students at different colleges of studies, age, and domestic versus international status was noted. The measure of health and well-being tested in this study confirmed that the four domains of well-being (mental, physical, university learning and economic) remain effective regardless of a university student's sociodemographic and study characteristics. These findings contribute to a theoretically robust and contemporary conceptualisation of health and well-being in higher education literature.

Findings of the study imply students' university journey should be supported with an integrated health and well-being solution. This is critical, as university students' health and well-being are influenced by the learning engagement in the classroom as well as surrounding societal issues. As has been portrayed in previous literature [14–16], the study found that the surrounding COVID-19 pandemic became an inherent aspect of students' health and well-being. Evidence of suffering in students' mental health, due to social isolation from university peers, family, and campus life was apparent. The university learning, particularly, the worsening balance between face-to-face and online study during COVID-19, was found to take a toll on students' physical comfort and concentration on study. In some cases, students' economic well-being suffered during COVID-19, as it became difficult to transition into secure part-time jobs and afford suitable accommodation. Furthermore, students found the university health and well-being support services to be lacking in proactiveness and not easily accessible. Students' experiences during the pandemic make a stronger case for supporting students with solutions across the mental, physical, university learning, and economic domains of health and well-being.

This study also noted a few defining features of integrated health and well-being solutions for university students. From the discussion of students' experiences of the university journey, it became apparent that health and well-being have a strong social feature. As had been noted in previous literature [11,19,31], this social feature incorporates support received through interaction with peers, teachers, and the community (beyond the university campus). Interestingly, participants in this study also touched on a face-to-face component of this social feature, that is, campus life. This notion of campus life was expected to be physically situated on the campus, countering feelings of isolation. Previous research has endorsed similar notions of campus life that can enhance students' quality of life and university belonging, providing a geographical surrounding of cultural, extra-curricular, and recreational activities [32–35]. Hence, universities should be prepared to promote health and well-being solutions with a combination of face-to-face and virtual approaches. An area worthy of future research is investigating the best approaches to offer social features in the suite of health and well-being solutions.

Another defining feature of integrated health and well-being solutions should be pro-active monitoring of students' needs in the mental, physical, university learning, and economic well-being domains. Through such monitoring, universities should offer greater engagement between academics, administrators, alumni, and students, using academic and non-academic agendas to provide long-term help to each other [15,36,37]. For instance, at the university under study, the mental/psychological well-being of students is identified as an area needing improvement, being the domain that received the lowest score among all the well-being domains. The mental well-being domain was also found to have the highest level of association with the physical well-being of students. At this university, initiatives concerning a sustainable lifestyle of students, including eating healthily, stress management, and resilience, and maintaining a balance between a host of issues, for example, sleep and study, and technology use and physical activities, should be explored as avenues for integrated health and well-being solutions [38–43]. More studies about how to operationalize integrated solutions across the domains of health and well-being of university students would be of great value.

Other defining features of integrated health and well-being solutions should be inclusiveness and continuity. As mentioned earlier, the study found variation in the level of health and well-being among students at different colleges and age-related cohorts. In line with previous literature [44], international students were also noted to suffer from lower levels of well-being than other student cohorts, due to COVID-19-induced racist notions that constrained social inclusion. These findings imply that the higher-education sector requires support from macro policies and a community-wide approach to student health and well-being that targets inclusiveness. In Australian higher education, while general interest in promoting student success through policy guidance such as equitable access to quality education exists, more concrete measures for specific student cohorts are needed [45]. Future studies should investigate the health vulnerability and well-being of each of the identified cohorts in this study, for example, by age, college of study, and citizenship status, and explore suitable concrete measures.

Health and well-being solutions should be in practice during pandemic as well as non-pandemic times. Continuity with health and well-being support is necessary to empower students for success in university life and beyond. As seen in this study and previous literature [11], universities should promote health and well-being through quality learning as part of their core business. Practices of reciprocal interactions between teachers and students in the classroom environment should be promoted to enhance students' well-being [38]. The embedding of a health and well-being curriculum through partnership with industry and co-teaching with experienced members in the community is another avenue to bring integrated health and well-being solutions to the university [46]. Additionally, this study advocates for universities to address students' mental, physical, and economic well-being needs so that students remain capable of contributing to the community's achievement of SDGs [44]. A university's role in supporting students' health and well-being and the influence of such support in the achievement of UN SDGs should be investigated in future studies. This study has certain limitations. The investigation took place during the COVID-19 pandemic; however, the study method did not distinguish the threat of vulnerability to students between pandemic and non-pandemic issues. While the COVID-19 pandemic had brought pre-existing health and well-being issues of students to the surface, not distinguishing the COVID-19 influence may limit the generalisability of the findings for certain contexts. The study was conducted through a self-reported survey by students in one university and had a low response rate (8%). However, no sampling bias was detected due to the low response rate. Finally, this study could not apply a validated tool to assess health and well-being of higher education students, as currently the biopsychosocial model of health is not supported with one such tool. Notwithstanding, the study findings endorse that a theoretically sound and regular assessment of student's health and well-being can advance a university's agenda to understand student needs and accordingly offer integrated support for students' health and well-being.

6. Conclusions

This study has clarified students' perceptions of their experience at university according to the biopsychosocial model of health, identifying the mental, physical, economic, and university learning domains of students' health and well-being. Hence, the study has been successful in a more holistic conceptualization of health and well-being, going beyond the usual mental and physical dimensions. As the four domains of students' health and well-being were found to be interrelated, in line with the theory of the biopsychosocial model of health, universities should advance student success by working in all these domains. This work should be done proactively, ensuring continuity, inclusiveness, and a balanced delivery of integrated health and well-being solutions through a combination of face-to-face and virtual approaches. The task at hand is to provide solutions that facilitate quality learning as well as provide a sustainable lifestyle for students. This is not an easy task: given the diversity in the cohort of university students, this implies that there will not be a one-size-fits-all solution with a uniform level of requirements across the mental, physical, university learning, and economic well-being domains. However, there is potential that offering integrated health and well-being support at university will empower students to pursue success across their personal journey at university and in the community.

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Article

"A Common Danger Unites": Reflecting on Lecturers' Higher Education Experiences during the COVID-19 Pandemic Using an Ethnographic Fictional Analysis

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Abstract: The sudden transition of Higher Education (HE) from predominately face-to-face to online delivery during the COVID-19 pandemic lockdowns placed many lecturers in unfamiliar situations. This study aimed to explore and represent the experiences of lecturers working in HE during this time. We used a storytelling approach to represent an amalgamation of experiences collated from lecturers. Data were collected using (i) a focus group interview, (ii) reflections on our experiences, and (iii) experiences alluded to by academics via online blogs. The data were presented using an ethnographic fiction. Salient experiences detailed throughout the ethnographic fiction include (i) challenges building a community between colleagues, academics, and students; (ii) concerns regarding the capacity of institutions and staff to deliver online; (iii) a lack of synergy between the expectations of staff to fulfil duties and the reality of being able to do so in time; (iv) the challenges of engaging students; (v) concerns regarding the accessibility of online learning for a diverse body of students; and (vi) challenges with work–life balance. The ethnographic fiction provides a voice for HE lecturers who candidly shared their experiences of working during the pandemic. Stakeholders are encouraged to develop their own interpretations of the story and apply these to policy and practice.

Keywords: higher education; COVID-19; creative non-fiction; digitalisation

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1. Introduction

While it is estimated that the cost of the coronavirus disease (COVID-19) pandemic to the United Kingdom (UK) will run into hundreds of billions of GBP [1], the implications of COVID-19 for society are immeasurable [2]. For many working in the UK, government strategies focused around national and localised lockdown, and for those working in education, including those working at universities, this meant enforced building closures [3]. In spite of this, the day-to-day business of learning, teaching, and assessment, for the most part, continued unabated, with many lecturers converting pre-prepared materials into online content at short notice [4,5]. For many, this was an unusual and often disorientating experience [2]; however the voices of those involved have not yet been appropriately captured and represented, and therefore the issues faced by these individuals are not widely acknowledged. Subsequently, to understand the challenges faced, this article aims to give a voice to these individuals by capturing and representing lecturers' reflections on their experiences of working in Higher Education during the COVID-19 pandemic.

A potential reason for lecturers not being heard is the fear and uncertainty generated by a lack of job security, with widespread redundancies continuing to sweep through the sector at an alarming rate as projected student numbers fall [6,7]. In such moments, alternative approaches to analysing and commenting must be taken to shine a light on important matters whilst protecting the anonymity of those involved. Consequently, this paper provides an ethnographic fictional analysis of lecturers' reflections on their experiences working in Higher Education during the COVID-19 pandemic. Before presenting this ethnographic fiction, the literature is reviewed with respect to (i) the move to virtual delivery, focusing on digitalisation, competence, and challenges, and (ii) topical issues of student engagement, collegiality, and work–life balance. These topics were informed by an iterative approach consisting of reviewing the available literature on the initial topic of how academics adjusted during the pandemic and underpinning the experiences alluded to throughout the data collection and analysis procedures. Next, the broader methodological landscape of this paper is outlined before culminating in an ethnographic fiction account. Conclusions are drawn, inviting the reader to develop interpretations based on their unique vantage point.

1.1. A Move to Virtual Delivery—Digitalisation, Competence, and Challenge

The 21st century has seen the proliferation of digital technologies, illustrated by the widespread use of mobile devices, social media, and cloud computing [8]. The impact of digitalisation has affected Higher Education, leading to something akin to a digital transformation [9–12], with students having increased expectations that universities utilise digital technologies synonymous with their learning experience [13]. While there has been a deliberate move in this direction, the COVID-19 pandemic thrust Higher Education providers headlong into providing for their students exclusively via digital interfaces [5]. Responses and solutions were many and varied from both institutions and those delivering, and in understanding this complex picture, the dominant focus in the literature has been on both the process of digitalisation within the sector and the educators′ digital competence [14]. This is significant to appreciate as competence has been seen to shape the direction and intensity of digitalisation [15,16].

The digital competence of educators is a regular topic of discussion in research and practice [17] and has been the focus of multiple studies [18–20]. Professional digital competence entails the ability to access and employ digital resources for pedagogical purposes [21]. In Higher Education, studies commonly find that lecturers demonstrate variable levels of enthusiasm and capabilities with respect to the use of digital technology and teaching online, which has an impact on the quality of delivery [22,23]. While this was reported to be the case during the COVID-19 pandemic [24], one of the positive consequences of moving to virtual delivery was that many lecturers significantly developed their digital competencies, even if it was out of necessity rather than by strategy or design [25]. While significant challenges were repeatedly noted, the willingness to embrace this change was strongly felt to ensure that students continued to learn under challenging circumstances (see [26–28]). The most notable exception here is a large UK-based study by Watermeyer et al. [2] in which university lecturers painted a less-than-positive experience of the rapid transition to virtual delivery. The UK educators reported higher levels of stress and seemed to have fewer positive experiences than those reported in the other surveys. Given the inconsistency in the findings in this area, further research is needed to enhance our understanding of academics' experiences of transitioning to a virtual platform. Developing our knowledge in this area will enable us to better support colleagues in developing their digital literacy skills in a climate in which Generation Z comprise the dominant generation entering the Higher Education system [29].

1.2. Student Engagement

Challenges in motivating and engaging students in virtual teaching sessions have been widely reported, see [27,30,31], with a majority of staff in agreement that collaboration and interaction with and between students is clearly greater with face-to-face delivery [26,32]. Such a finding is perhaps unsurprising given that academics have strongly entrenched notions of what constitutes effective teaching and learning in Higher Education, having established well-trodden pedagogical identities [33]. Such changes are not always welcome and can be hard to assimilate [30].

The recent landscape has indicated that traditional modes of delivery in the 21st century may no longer be fit for purpose [34,35] and could have contributed to a lack of engagement in the wider lecturer–student relationship [36]. The findings of some studies have concluded that lecturers may need to change the way in which they interact to make the most significant impact here [37]. The use of a wider array of tools such as quizzes and polls in virtual classrooms are examples that may contribute to addressing some of these challenges [38,39].

1.3. Collegiality

With the move to virtual delivery, concerns were raised that with staff being physically kept apart, they would behave in a less collegiate manner, focusing more on their own immediate needs reflecting their isolation and mental health [40,41]. Despite such concerns, moving to virtual delivery during the pandemic was reported to bring academic communities closer together [26,42]. Such findings build on pre-pandemic work in this area in which virtual environments have been shown to facilitate knowledge sharing amongst the academic community [43,44]. An interesting new finding reported in the current situation is that younger, less experienced members have gained value more rapidly as they generally have been more technologically adept and flexible than their older, more experienced counterparts [2].

1.4. Work–Life Balance

Work–life balance refers to how individuals experience and negotiate the intersection between professional and personal responsibilities [45]. It is a concept of increased importance for the 21st-century workforce [46–48], and "getting it right" has been shown to boost the quality of work [49], psychological well-being [50], and employee commitment [51].

Due to the COVID-19 pandemic, most of the workforce, including the education sector, were required to work from home [52,53], which impacted established work–life balance patterns [54]. Studies in this field have overwhelmingly reported a negative impact on Higher Education staff [2,34,55,56]. For example, Watermeyer et al. [2] indicated that the customary parameters which separate work from personal lives were eroded into a timelessness of being permanently on-call to large groups of students. Compulsive working practices continue to be reported, reflective of the "hyper-professionality" [57] that is typical in the sector. This additional time commitment, coupled with the realisation that online preparation is far more time-consuming [58], has significantly impacted those with parental responsibilities [59] and is exacerbated at moments by additional requirements such as enforced home schooling. Many in such circumstances reported their frustration and resentment at being unable to adequately cater to both their students and their own children [2].

2. Methodology and Methods

2.1. Guiding Philosophy

This research was guided by our constructionist epistemology. From this perspective, we assumed that knowledge is constructed by individuals interacting within the social world [60,61] and that the process of understanding involves a shared generation of knowledge between people in relationship [62]. We therefore recognise the active role that we played within this research and acknowledge that the findings presented below are the result of a co-construction of knowledge between ourselves, the participants, and other resources we engaged with throughout the research process [61]. In light of this, we are mindful that our findings represent only *one* interpretation of this topic. In relation to ontology, we assume that our understanding of the world is informed by our own unique experiences [63,64], and subsequently, see the value in capturing and representing experiences from multiple vantage points.

2.2. Research Approach

We used a storytelling approach [65] to represent the challenges academics working in Higher Education experienced during the COVID-19 pandemic. We view this approach of data representation to be positioned within a broader narrative-inquiry framework in which stories are valued for their ability to coherently capture, represent, and make sense of our own and other people's experiences of, and meanings ascribed to, life events [66–68]. This approach aligns with our constructionist epistemology because stories enable people to create and communicate meanings to make sense of their lived experiences [69]. An ethnographic fiction (also referred to as creative non-fiction), defined as "a type of creative analytic practice that tells a story which is grounded in research data and draws on literary conventions" [70] (p. 59), was chosen as the method of storytelling in this research. There are contradictory perspectives amongst academics regarding the term "fiction" when used within scholarly activity [71,72]. We adopted Sparkes [73,74] perspective on ethnographic fiction in that the story which we developed in our research is grounded in systematically collected data on real events and people.

2.3. Gathering the Data

The story presented in this manuscript consists of an amalgamation of experiences from academics based at different Higher Education institutions. These experiences were not captured using the traditional methods of recorded and transcribed interviews but were developed in the wake of a series of formal and informal conversations which the authors had with academics during the COVID-19 pandemic and upon the absorption of academics′ blogs referring to their experiences with Higher Education during the pandemic. What follows is a description of the methods we used to gather these experiences.

2.3.1. Focus Group

Three academics were recruited via purposive criterion sampling [75] to participate in a focus group. To be eligible for this part of the study, the participants were required to (1) have been working in Higher Education during the COVID-19 pandemic and (2) have networks with others who were working in Higher Education during the pandemic. These criteria were necessary to recruit individuals who could co-construct knowledge relevant to the aims of the study. At the time of data collection, participant one was a 32-year-old female with ten years of experience working as a lecturer in Higher Education and was a mother to a toddler. Participant two was a 51-year-old male with three school-aged children and had worked as a lecturer and course leader in Higher Education for ten years. Participant three was 29 years old and had 5.5 years of experience working in Higher Education as a lecturer.

A focus group method was chosen because of the opportunity to discover novel insights [76] and gather rich, in-depth data about the group members' experiences and perceptions towards a particular phenomenon [77]. We used Krueger's [78] guidelines when deciding on the focus group size, and the participants' backgrounds, the complexity of the topic, and the moderators' levels of expertise were taken into consideration.

The focus group was conversational (i.e., unstructured) to evoke the participants' stories [72], enabling them to communicate their experiences through their own perspectives and on their own terms [79]. In accordance with this, the focus group began with a broad, open-ended question to the participants (i.e., "Tell me about the challenges you and other academics who you have interacted with over the last 12 months have experienced within your role as a consequence of the COVID-19 pandemic?"). The moderator's role was to encourage interaction between the participants and to guide the discussions [80]; subsequently, whilst they let the dialogue flow between the participants, when appropriate, they followed up on responses with further unstructured questions. The focus group was conducted online via Microsoft® Teams and lasted sixty minutes. It took place in March 2021 during the third national lockdown when Higher Education institutions were required to deliver all content virtually [81]. The focus group was not audio recorded, but both authors made detailed notes during and after, and these notes were included in the data analysis.

2.3.2. Online Blogs

We also drew on experiences disclosed by academics via online blogs. The use of online blogs to access individual narratives has been advocated by academics conducting research in a variety of fields including health, e.g., [82], sport, e.g., [83], and education, e.g., [84]. We obtained relevant blogs using web links provided by the academics who participated in the study's focus groups and by searching Google. We used search phrases including, "lecturers and COVID-19 and blog", "Higher Education and COVID-19 and blog", and "academics and COVID-19 and blog", to locate blogs which were relevant to the aims of this research. The following exclusion criteria were used to eliminate blogs which lacked relevance for the focus of our research: (i) blogs which were not reflective of the study aims and (ii) blogs written by individuals who were not working within Higher Education institutions. When retrieved, blogs which met the inclusion criteria were saved on the second named author's laptop. The blogs included in this research were unsolicited in that we did not request that these blogs were developed for our research because doing this can result in response bias [82]. The blogs were available in the public domain; however, the names of the individuals who wrote the blogs were not included in the story presented below because this story was a composite and included fictional characters. A total of twenty-eight online blogs were included in the sample. We ceased collecting data from the online blogs at the point at which we felt we had gathered enough data to address the aims of our research and develop a complete story representing academics' experiences of working in Higher Education during the pandemic. This approach to data cessation aligns with suggestions from Saunders and colleagues [85]. Data collection for this stage of the project took place from March to September 2021. At this point, the UK was coming out of a national lockdown, with restrictions regarding the number of people at gatherings in place, and only practical sessions were allowed to be delivered face-to-face at University; subsequently, the majority of teaching remained online [81].

2.3.3. Reflections

We also reflected on our own experiences of working in Higher Education during the pandemic. This approach is supported by Selbie and Clough [86], who embedded Selbie's personal and professional experiences within their ethnographic fiction on the educational ideas of Comenius and Isaacs. As part of this, we drew on our recollections of informal conversations that we had with other academics (based at various Higher Education institutions) about their experiences of working during the pandemic. This approach is compatible with our constructionist epistemology and aligns with the characteristics of a narrative inquiry in that humans are assumed to be relational beings, and so the narratives which describe and meanings which we ascribe to our life experiences are achieved via social exchanges and relationships that we have with others [87,88]. We made notes of our reflections, and these notes were used within the data analysis. We engaged in this process from March to September 2021.

2.4. Situating the Authors

Within qualitative research, a researcher's background can influence each stage of the research process [89]. Our biographies and positioning are of particular interest in this paper because we both worked within Higher Education during the COVID-19 pandemic and therefore have first-hand experience of the issues explored within this manuscript. Subsequently, we are situated as "insiders" within the research [90]. Our embodied experiences of working in Higher Education during the pandemic informed the research aims, methodology, methods, and ethnographic fiction, and consequently, we acknowledge that our personal interpretations were omnipresent during each stage of the research [89,91]. We maintained a reflexive stance, making regular reflexive notes [89] and engaging in reflexive discussions, to acknowledge how our subjectivity contributed to the co-construction of knowledge in this paper [72]. What follows is a transparent overview of our biographies so that you, as readers, can understand the positioning from which we approached the knowledge presented within this manuscript.

The first named author has twenty years of experience in teaching and managing in Higher Education across multiple institutions. He is a father to a teenager who had spells of both being in school and having to manage home learning. He was required to manage an academic team to deliver the provision of Higher Education during the global pandemic.

The second named author has over ten years of experience teaching in Higher Education. She is a mother to a toddler and a school aged-child and was on parental leave with her firstborn at the time when the COVID-19 pandemic was first announced. She returned to work in July 2020. When returning to work, she was faced with the challenge of being a working mother and delivering Higher Education during a global pandemic.

2.5. Crafting the Story

To reduce the risk of formulaic, straightforward, and predictable research being "robotically" developed, Smith and colleagues [68,70] advised academics to avoid a facsimile approach when creating ethnographic fictions. Consequently, there are no prescriptive guidelines for creating ethnographic fictions [92]. Instead, it is recommended that academics clearly outline the steps that they take when developing their stories [93]. While developing our ethnographic fiction, we adopted positions of both story analyst and storyteller. Given the complexity surrounding the dichotomy of these terms, researchers can move between perspectives when creating ethnographic fictions [70], and this is a common approach used [94,95].

2.5.1. Stage 1: Inductive Thematic Analysis

We adopted Braun and Clarke's [96–99] reflexive approach to thematic analysis to organically and recursively explore meaning, and analyse patterns, across our data set. We applied inductive reasoning during this analysis, encouraging us to construct new creative knowledge [72]. First, we compiled the data (i.e., the online blogs and the notes taken during the focus groups and from our own reflections). Then, we recursively conducted Braun and Clarke's [96,98] six stages of reflexive thematic analysis: (1) familiarisation with the data, (2) generating inductive codes, (3) grouping codes into coherent themes, (4) reviewing and refining the themes, (5) defining and naming the themes, and (6) producing the manuscript. We conducted the analysis at a latent level, exploring the underlying meanings of the data when developing the codes. During the sixth stage of the analysis, we used the themes to construct an ethnographic fiction. The codes and themes can be viewed within Appendix A.

2.5.2. Stage 2: Ethnographic Fiction

A multi-stage iterative process was used to develop the ethnographic fiction. This involved the first named author drafting, editing, and redrafting the story multiple times, engaging in reflection throughout the process. The codes and themes developed during the thematic analysis were used to craft the story, with literary techniques being used to weave the themes into the story.

The story was assembled as a conversational dialogue with three composite characters engaging in a discussion with each other. We chose to develop three characters which aligns with existing research that used similar representation methods to those adopted in our study [100]. The use of three perspectives enabled us to be appropriately critical and triangulate in equal measure (please note that these characters were not direct representations of the three individuals who participated in the focus group interviews or of ourselves but include an amalgamation of characteristics from an array of individuals working within Higher Education with whom we interacted during the pandemic). The characters were developed to represent voices that reflected aspects such as teaching experiences, family circumstances, IT confidence and competencies, and general perspectives on their situations. The characters were designed to demonstrate polyphony through a dialogical narrative, enabling distinctive perspectives and experiences to be represented simultaneously through the interaction of different character voices within one all-encompassing story [67,101]. Adopting this approach is believed to enhance a story's resonance for its readers and enable researchers to present differing narrative resources that represent multiple ways of thinking, feeling, and behaving [67,101,102]. In line with this, the story was crafted to include three distinct characters interacting with one another around a shared topic, with the various experiences and perceptions of working in Higher Education during the pandemic being entwined throughout the characters' conversational dialogue. While designing the three characters within our story, we carefully considered the backgrounds and experiences of the academics who we interacted with during the pandemic. We chose to keep the biological characteristics of the characters neutral (e.g., gender, ethnicity) with the aim of increasing the audience′s ability to relate to them.

The story's plot and the metaphors employed throughout the story were underpinned by the themes developed within the thematic analysis. When crafting the dialogue between the characters, we considered how humans interact with one another when in conversation. Although the story is based on real-life experiences encountered, viewed, or communicated to the authors, some of the content within our story was deliberately accentuated to help showcase the themes developed during the thematic analysis. This closely aligns with the approach adopted by Jones [103], Nelson and Groom [104], and Roberts [100] in their ethnographic fictions.

The story was shared with the second named author, who acted as a critical friend and confirmed that it was cohesive, concise, enlightening, and aligned with the themes developed during the thematic analysis, thus checking for the representation of the research findings within the story [105,106]. Feedback during this process resulted in the first named author making further edits to the story. Once both authors were happy with the story, it was shared with the three focus group participants [106]. Critical discussions were held with these individuals to gain their initial reactions to, and reflections on, the story [107]. The story was also shared with four critical friends who, after reading it, engaged in a reflexive discussion with the second named author [107]. These critical friends were academics who taught within Higher Education during the pandemic, thus enabling us to capture the critical thoughts and reactions from individuals who may be able to use the story to inform their practice.

3. A Fictional Narrative—Reflecting on Lecturers' Higher Education Experiences

Alex, Kelly, and Morgan are all lecturers at different Universities in the UK. Prior to the first COVID-19 lockdown, their predominant mode of delivery at their respective institutions was face-to-face. Morgan also had the experience of delivering an online module as part of a distance learning course. They have known each other professionally for a few years as part of subject community and have agreed to meet on Zoom one morning following a recent national subject webinar. The purpose of their meeting is to scope out the hosting of a special interest group day.

[Morgan is hosting the call and Kelly is the first to join]
Morgan—Hi Kelly. How's it going?
Kelly—Hiya. All good thanks. Just dropped the kids off.
Morgan—Is the sun shining where you are? It's a lovely morning here.
Kelly—Not yet. It's supposed to be a nice day but we've still got cloud at the moment.
[Alex joins the call.]
Alex—Morning both. Sorry I'm late. I couldn't get the link to open. Got there in the end. Did you enjoy the webinar yesterday?
Kelly—It was ok. Not much new really. I'm not sure I'll go to the next one.
Morgan—I quite enjoyed hearing Hilary speak. I've not heard her before.
Alex—Yes she's always good value. I first met her at a research seminar about 25 years ago and you could tell back then she'd be a name in the field. I am friends with her former PhD supervisor.
Kelly—Is that Derek?

Alex—It is. We go back a while.

[Everyone on the screen smiles in acknowledgment of Alex and Derek's relationship, and attention then turns to the focus of the meeting.]

Kelly—Well, thanks both for your time this morning, and thanks Morgan for sorting the link out for us. I've been having a think after the webinar and I think we should be able to put enough people together for the special interest group day. What do you think Alex?

[Alex appears to be talking as displayed on the camera, but there is no noise coming from the speaker.]

Morgan—You're on mute Alex.

Alex—Sorry, I'll try again...I'm just not sure if I'm honest. Is it really worth it? I was wondering if it was worth waiting a year and doing it face-to-face. I mean, I don't know about you when you're delivering a lecture, but it's just such hard work. The lack of feedback is deafening. I'm not sure doing a research session online would be that different from some of the student sessions I've done. You can't read the room or adjust your points, which I just feel seems a bit empty. I feel like you end up putting far more into developing, designing, and delivering these sessions than you get out of them.

Morgan—I think we've been very lucky with some of the students we have to be honest. You've definitely gotta be innovative in how you engage students. I do feel I'm working two and half to three times harder per class though. I've found it completely depends on the module you are teaching as to whether or not it is more challenging to engage the students. For some modules I've actually found I've had more engagement from students than I have historically in a classroom.

Kelly—I hear what you are saying Alex. If we try and do it the same way we would have done it before COVID it would be a bit dry. But there is some good stuff going on out there. For me it's about trying to simulate, rather than emulate. Don't try and do what you can do in a face-to-face session, but try and simulate it to get the same outcomes. This is something we should really strive for, I'm not sure we have actually had enough time to make that change because of the amount of content we've had to develop for virtual delivery in so little time, but starting to implement it in this session could be a starting point.

Alex—Some of that is about technological competence of each of us though. I'm sure some of the stuff young Morgan is doing, I've probably never even heard of.

[Everyone smiles at Alex's self-deprecating comment.]

Alex—What's one that the younger ones use at our place? Prezi I think it's called. Have you tried that one Morgan?

Morgan—Yes I use it sometimes. It's alright, depends on what I need to get my point across I suppose.

Alex—How did you learn to use all this technology in your teaching? PowerPoint is about as much as I can do.

Morgan—I just try stuff out and see what works. There's some good online tutorials out there on it if you fancy learning how to use it Alex.

Alex—OK then, I'm sure I can throw something together for the day with what I already know. I'll muddle through.

[Everyone smiles at Morgan and Alex's comments, seemingly acknowledging that Alex is not likely to take that advice. Kelly steers the conversation back to its main purpose.]

Kelly—So do you not feel others would be up for it Alex? I was thinking maybe Paul, or Gemma, or Michael G might do sessions.

Alex—I'm not sure you'd get Paul. He was struggling a bit the last time I spoke to him.

Kelly—Oh no. Is he ok?

Alex—Yeah, I think so, but you know what it's like switching to virtual delivery. Like Morgan said, everything takes twice as long to do, and he's got two little ones at home he's been entertaining.

Morgan—Wow. I can imagine it's really hard having to balance children at home whilst working. I've found it challenging to segregate work and life myself, it all just seems to merge into one, there's no separation between them, and I don't even have kids on top of work to contend with.

Kelly—Yeah, I don't envy him. My three have been bad enough, but at least they're older. It did get really hard when I was having to home school them though, the school provided some material, but I really had to make sure they were engaging in it—balancing my work with their schoolwork was really tough.
Alex—I guess that's where I'm quite lucky in a way, with living on my own. I have fewer distractions, and when I'm finished for the day I can just shut the office door, and I'm then on my own time, with having the added bonus of no travel. Weirdly I seem to have more time than before. I guess that's just down to the lack of commute. That said, I've always been pretty good at the work-life balance.
Morgan—Yeah, that's true enough, being stuck at home all the time makes you feel like you have all the time in the world; really though with the added workload because of the shift to online teaching, I feel we have no time. . ..Going back to your question though Kelly, I think Gemma would be up for it. I'd be happy to ask her. I've known her a while.
Alex—That sounds like a good idea and I'm happy to approach Michael, so that's two at least to start us off. Is there anyone else at your place Kelly that could. . .
[Alex stops mid-speech as there is a noise in the background coming from Kelly's mic, and a dog starts to bark.]
Kelly—[*Talking over the barking dog.*] I am so sorry, that must be the post, if you could just give me a second, I better run and get it because if not the dog will only keep barking.
[Kelly mutes the mic and disappears from the screen.]
Morgan—Wow, sounds a bit chaotic there. To be fair, I'm surprised my dog hasn't started barking yet too.
Alex—Yes, it happens quite often in our weekly academic team meetings. My biggest trouble with noise here is that the neighbours are doing DIY at the minute and they start drilling or hammering as soon as I start a meeting. We have got lucky today though, all is quiet at the minute.
Morgan—That must be a bit frustrating. It's brilliant how understanding everyone is though isn't it? I guess we all have different but similar challenges.
[Looking flustered, Kelly returns to the screen and turns the mic back on.]
Kelly—I am really sorry about that. At least it wasn't the kids this time, that's the usual. What was it you were saying Alex?
Alex—No problem, I was just saying that I would approach Michael which gives us two, but is there anyone at your place who could do a turn?
Kelly—I'm not sure to be honest. At one level there's lots of goodwill around and I could probably ask, but just like Paul, there's a lot who I don't think have much capacity in their work—life situation. We've had a couple of new people join who have good CVs, but I obviously haven't had a chance to meet them yet. Well on Teams I have, but you know what I mean.
Morgan—I hear you, but if we don't try and include them in opportunities like this, how can we actually get to know them? Personally, I think it would be a great chance to liaise with the new colleagues.
Kelly—That's a fair point. I think I've definitely interacted less with some colleagues since the shift to online, simply 'cos I don't see them in passing or in the office, and I've not needed to have that interaction as part of the job. You just get on with it I suppose, don't you?
Morgan—For sure. I feel oddly distant from some people compared to before because of that lack of face-to-face interaction in the office, yet at the same time somehow part of tighter, broader group. More virtual meetings within modules teams and WhatsApp groups have really helped here in some instances. That said, I've definitely thrived on neglecting working within some groups.
Alex—Nothing like feeling unappreciated to bind us together, eh Morgan? A common danger unites and all that. . .
Kelly—Any excuse to get some Aristotle in there Alex. [*All grin knowingly.*]

Alex—Well I'm consistent at least. Anyway, are you guys still ok to host it Kelly? I keep seeing your place getting the bad publicity on the TV, but I assume that's not your campus.
Kelly—Yeah, we'll be good Alex. I can't complain really, to be honest, with the challenges currently faced in the sector I am really appreciative that I've still got a job and all that [*Kelly smiles awkwardly.*]. There's a funding pot for this anyway. All the noise is happening on main site with student halls and unions etcetera but nothing much here.
Alex—That's good then. Any thoughts as to when might be best? It would be nice to get a date in the diary. Give people something to look forward to.
Kelly—My best guess was between Easter and early summer. How does that sound?
Morgan—I can't see that will work I'm afraid. The rhythm of a normal year is one thing, but the rhythm of a COVID year is quite another. Our non-detriment policy, and I'm sure it's the same elsewhere, means the students have such flexibility that they can hand in weeks late and we still have to mark it by the original deadline. The worry of not being able to meet the deadlines though—it completely goes against who I am as a person and how I work. It makes it quite challenging. I can't see there being capacity until into the summer or even into the start of the next term to be honest. . ..but we should try and find a date. I do agree with Alex that it would be nice to have something to look forward to.
Alex—Listening to me is now your idea of something to look forward to? [*Everyone laughs.*] Oh how times have changed.
Morgan—Well it's a change from Groundhog Day (Groundhog day refers to a film where a weatherman finds himself reliving the same day (i.e., Groundhog day) on a continual loop. In the story presented in our research this phrase signifies a situation where the same monotonous experiences are repeatedly) isn't it.
Kelly—Would it change anything if we delivered it virtually Morgan, rather than face-to-face?
Morgan—I don't think so. Marking is marking, so people's time, or lack of it, is what it is.
Kelly—Before term starts then. Yes?
Alex—Agreed.
Morgan—Works for me.
Kelly—And virtual?
Morgan—Yup.
Alex—Probably safest. If we deliver it virtually, we may get more attendees. I don't know about you, but I'm still a bit anxious about socialising too much—the idea of teaching face-to-face really scares me because we're going to be inside, and we won't know what other people have been doing or who they've been around. So, it does scare me.
Morgan—I can see why you might feel that way, I'm the opposite, I'm really excited at getting back into the face-to-face teaching again, I've really missed it.
Kelly—Yeah, same...And what about advertising? Just mailing lists or something more?
Morgan—How about using Eventbrite? I've set a few things with that now and it seems to work fine.
Kelly—I'm happy with that. Alex?
Alex—Let's use both I would say. They seem like good ideas which are likely to attract people, but I'm still a bit worried about getting people to attend the day. It's like we were saying earlier about the students, isn't it? It can be so challenging cracking attendance and engagement in a classroom, how on earth do we do it online? It's difficult to tell if they are engaging with the online lectures as it is, never mind with the other resources we have to offer. What's to say this will be any different for this day?
Morgan—It'll be a challenge for sure, but I've been to a few really good online networking events. Some event formats I've seen could work well. Something that might add a bit more of a community feel. [Kelly appears agitated on screen]
Kelly—That sounds good Morgan. Sorry to be rude but I'm just a bit conscious of time and I've got another meeting in five and if I don't get up now and make a brew then I'm not likely to either drink or move for another couple of hours. So can you hold that thought and perhaps explain some of those ideas next time Morgan?
Morgan—Sure.

Kelly—Can we pop another date in to meet before the end of the month? [Both nod]. Is this day and time good for you both in say two weeks time? [All check their Outlook calendars at the same time].
Morgan—Works for me.
Alex—Yes, I can do that.
Kelly—Great. I'll send you an invite shortly.
Morgan—Would either of you mind if I planned to attend the next meeting on the move? I just find that when we were delivering face-to-face I'm usually stood up moving around for several hours in the lectures and seminars, and now I just sit on my bottom for the duration, and it makes me feel less good. I've been trying to do what our well-being team suggest and move around every so often, but I'm not always that great at it because I feel like I am losing progress on my work. It would be great if I could try and do some of my meetings on the move, like on a walk or even just stood up, I think it will really lift my mood, but I will only do it if you are both ok with it?
Alex—Sounds like a great idea to me, no problem with it at all.
Kelly—Sounds wonderful—I may even have to join you with that idea. Right, nice one, thanks again for taking the time to meet today. I really appreciate it. I'll see you soon.
Morgan—Bye. Take care.
Alex—Bye everyone. Speak soon.
[Kelly leaves the call, followed by Morgan and then Alex.]

4. Discussion

The purpose of this research was to extend our understanding of Higher Education experiences during the COVID-19 pandemic. We addressed this by capturing academics' experiences and perceptions of working in Higher Education during the pandemic. We chose to represent these experiences using an ethnographic fiction for numerous reasons. First, ethnographic fictions can provide a rich insight into the complexity and ambiguity of lived experiences from a unique perspective [66,108]. Using a conversational dialogue in our story, we were able to simultaneously showcase different perceptions and experiences of working from home during the pandemic. Second, the accessible, colloquial language used within ethnographic fictions enables information to be presented in an understandable and engaging way for wider audiences [66,92,109,110]. Third, due to the fear and uncertainty associated with the lack of job security for academics working within the Higher Education sector [6], we felt it was important to provide a means through which individuals would feel safe to voice their experiences. Stories protect the anonymity of those who share their experiences [111]. The ability of the story to achieve this was demonstrated by one of the participants who, after reading it, stated, "I was trying to work out which character best reflected me, but the good thing about it was I couldn't spot it, it was interlaced really well. It kept us anonymous whilst capturing the key points. Whilst there were areas where I was nodding and going, 'yes that's how I feel, there was no way I could spot myself in it." This was unanimously supported by all of the participants who suggested that they could see their "reality" within the story but, at the same time, could not identify themselves.

Finally, stories promote a deeper level of intellectual engagement by encouraging audiences to think with the findings as opposed to thinking about them [112,113]. In accordance with this, we adopted a *storyteller perspective* when discussing our ethnographic fiction because we view our story as being inherently analytical and theoretical by itself [114,115]. As such, we do not offer a traditional discussion where our story is interpreted in light of the existing literature. Instead, we chose to "show" rather than "tell" our story by presenting it on its own as it is [115]. As Lewis [116] (p. 831) suggested, "stories are brought to life though the storyteller; however, the story itself has a life that is given to the teller and the listener through the telling." Corresponding with Frank's [67] perspective, we wanted to let our story breathe.

We therefore encourage you, as readers, to think and feel with our story by contributing your own questions, answers, and experiences to it as you read it [105,109]. In doing this, we are relinquishing control to you, enabling you to construct your own meanings, interpretations, and evaluations of the story in accordance with your unique vantage point [106,115]. Indeed, when taking this approach, it is likely that you will each make different interpretations of the stories based on your life experiences and background [105]. In light of this, we encourage you to reflect on the ethnographic fiction presented above and apply it to your own life as you see appropriate.

In adopting this approach, we are encouraging you to think with our story, rather than telling you about it. According to Frank [117], thinking with a story prompts readers to engage in reflection on that story. Numerous academics, e.g., the authors of [70,108,111], have acknowledged the benefits of using stories to disseminate evidence-based information because by prompting reflection, they can facilitate dialogue, and teach, remind, and reinvigorate people. Subsequently, if you, as readers, embrace the above invitation, the story presented in our research has the potential to stimulate reflection and provide a platform to instigate open conversations and discussions regarding the experiences of academics during the COVID-19 pandemic.

To offer some initial support for this possibility, we now draw on the critical thoughts and reflections of the focus group participants and our critical friends with whom we engaged in reflective discussions following their consumption of our story. Their responses to the story were unanimously positive and encouraging. To provide more detail, the critical friends and participants indicated that the story instigated reflection within them, provoking thoughts and stimulating questions about their applied practice. For example, one individual stated, "The story made me question my own practice, am I doing enough to enhance my digital literacy, am I watching videos and teaching myself to make my sessions more engaging?" Furthermore, another individual commented:

> "The story made me feel reflective, I was able to contextualise it to my own lived experiences and link it to my own frame of reference. So, for example, I've been asked to support with some staff training in a few weeks, and we need to do an activity to bring all the staff together, and there were elements of the story which really got me thinking about and reflecting on how I will do that."

The same individual suggested that the story could act as "... a catalyst for reflection, which people can use to help reflect and hopefully make sense of their experiences." Such quotes demonstrate that the story presented in this research has the potential to stimulate intellectual responses from the audience and therefore has the potential to be impactful for key stakeholders [109]. Indeed, the potential impact of this story for key stakeholders was demonstrated by one critical friend who stated, "Reading the story normalised my experiences. It made me feel comforted because it was nice to see that other people have also been thinking and feeling this way and that it's not just me. Not many people will discuss this sort of thing because you just don't get the opportunity to. So, I really think the story could create a sense of community and help people realise that it's not just them feeling this way, it certainly did that for me". In addition, the potential impact of the story beyond the Higher Education sector was suggested by one of the participants, who stated:

> "I read through it and it reminded me "oh yeah, that was a moment of promise." Then I thought about how the rush back to normal has meant that a lot of the lessons which we could have learnt as a sector has been pushed to the wayside because we want to go back to how it was, because how it was had to be better; and it was in a lot of ways, but it also wasn't. I think that rush back, not just in Higher Education, but in loads of things from sport attendance to political power shows, has meant lots of lessons we could have learnt have been put aside. For me in particular, I think a good lesson to take from the story is that it shines a light on different expectations placed on different staff with different private life situations. So I think one of the things that people could take for future applied practice would be to provide compassionate timetabling taking staffs input in the timetabling and doing it with more empathy. This could ensure that people who

have other responsibilities, such as children, are scheduled to work in a way that helps them perform the best in their role."

Moreover, cumulatively, the critical friends indicated that they could resonate with the story. For example, one individual commented

> "There was a lot of elements of it that resonated with me, both in terms of the experience that the participants described, but also the way that they were discussing that experience. I think if there was one thing that particularly stood out was the concept of a 'them and us', and the online world potentially creating a barrier and taking away that ability to collaboratively learn in the classroom. That particularly resonated with me because of my teaching approach and I felt that that was absolutely grounded in reality".

Another individual stated, "I thought that it was reflective of wider conversations I've had within Higher Education about working through COVID and the impact it's had on HE experiences which I've gone through and colleagues have gone through. It just spoke to a lot of like shared truths I think". Comments such as this suggest that our story has the potential to offer evocative representations of data that are meaningful to key stakeholders and thus suggest some degree of resonance within our story.

The story also appeared to evoke emotional responses amongst our critical friends and participants. For example, one individual stated: "I was smiling when I was reading it cause it just felt like people I know having a conversation that I feel familiar with. I felt like 'yeah, I agree with these people, I understand these people and we've got the same opinion.' They also felt like real people which was crucial as well." Such responses support suggestions that creative non-fiction methods of data representation can be used as a means of eliciting readers' emotional reactions [70,92].

Overall, using a storytelling approach, this research has enabled us to represent the experiences of practitioners working in Higher Education during the pandemic. Feedback from the key stakeholders and participants would suggest that the story presented in this research (1) is reflective of real-life experiences, (2) has the potential to stimulate emotional and intellectual responses from an audience, (3) has the potential to be impactful both within and beyond the Higher Education sector, and (4) offers an opportunity for silenced voices to be heard. In presenting our findings using storytelling methods, we hope that readers of this research can consider the transferable nature of this story with respect to their own lives and that it will stimulate conversations amongst academics, having positive implications for those who currently work in Higher Education or plan to work in Higher Education in the future to enhance their practice. Whilst we encourage you as readers to engage in this process, it is important to be mindful at this juncture that the findings presented within our story are only able to offer a small window into the complex and multifaceted picture of what happened during the pandemic, what was left behind after the pandemic, and what continues to persist as a result of the pandemic.

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Appendix A

Table A1. Codes and themes developed within the thematic analysis.

Codes	Subthemes	Themes
A lack of synergy between additional time given to students to submit work within no-detriment policies and the length of time academics are provided to provide feedback and grades.	A battle of conflict: expectations versus reality	Challenges experienced at institutional and national levels
A misalignment between the flexibility provided to students for attendance and assignments and the delivery requirements for academics (e.g., feedback deadlines, delivery deadlines).		
An overreliance of academics being over-workers, over-thinkers, over-committers, and over-learners.		
Preconceptions that academics can transition to online delivery with little training, which conflicts with the reality that this is not necessarily the case for all academics.		
An imbalance between the time expected to put together content for online learning and the time it actually takes to prepare for online sessions.		
From the outside, it may have appeared as if infrastructure guided the process of delivery, but in reality, the frontline staff, the academics, the library staff, and the academic support staff made the sudden shift to online delivery work.		
Concerns regarding a lack of capacity at institutions to be able to deliver online learning.	The capacity to perform: challenges associated with the capacity to be able to deliver online teaching	
A lack of auto-captioning software resulted in a disparity in the ability to offer online sessions with subtitles to students.		
Variations across institutions with respect to what students have access to and when—is this due to differences in the capacity to deliver online across different institutions?		
Academics are faced with the challenges of not being able to conduct field trips or deliver practical sessions.		
Online learning results in an inability to capture attendance and engagement like in the classroom.		
Uncertainty regarding whether additional work is being recognised.	"You're welcome": the absence of recognition for hard work	
A perceived lack of acknowledgement for meeting high expectations.		
A perceived lack of appreciation from individuals in superior positions.		
A lack of acceptance and appreciation for the changes that needed to be made.		
A lack of training to prepare academics for online delivery.	"Sink or swim": support available for staff during the transition from face-to-face to online delivery	
Uncertainty regarding the transition back to face-to-face delivery.		
A loss of identity for experienced colleagues due to uncertainties about how to deliver content online.		
Variations in technological competencies across academics.		
Many academics trying to emulate (i.e., imitating face-to-face delivery online) rather than simulate.		
A lack of time and support for the online transition resulted in academics simply copying what the strategies they employed when teaching face-to-face when delivering online		
A lack of knowledge makes engaging in innovative, accessible, and original teaching in online environments challenging.		
Some academics find online delivery difficult because of a lack of training.		
Variations in lecturers' ability to deliver online teaching, with some staff lacking confidence and skills.		
The usual rhythm of an academic year changed, making it naturally destabilising for someone who was very used to that rhythm.	Navigating an unstable environment: when there is conflict between policy, the ability to meet deadlines, and staff self-identity	
The addition of a non-detriment policy made it impossible for deadlines to be met, and not meeting deadlines conflicted with some academics' identities.		
Belief that despite the challenges, academics currently working should be grateful for this due to the redundancies being made in the wider sector.	Safety in an academic storm	
The lack of funding in academia.		

Table A1. *Cont.*

Codes	Subthemes	Themes
Despite the lack of face-to-face connections, the academic team have become a stronger unit working together collectively.	A shift in subcultures: subcultures across colleagues have changed since the transition to virtual working	Working alongside colleagues in a virtual environment
Collegiality between colleagues is visible at a difficult time.		
Changes in the colleagues with whom academics are interacting and how often these interactions occur due to subcultures being developed across the team.		
The use of impression management with colleagues.		
Some interactions between colleagues are lost due to an inability to see these individuals in passing.		
Challenges with bringing in new staff members and embedding them into a team when working virtually.	"Alone we can achieve little, together we can achieve lots": the challenges of building a community amongst colleagues in a virtual environment	
Challenges with building a sense of community among staff.		
Virtual activities are offered to try and increase a sense of community among colleagues, but the activities are not everyone's "cup of tea".		
In the classroom, students and lecturers become a unit, but it is difficult to establish this online.	The challenges of becoming an "us": trying to establish a community between students and academics and students and students in a virtual environment	Engaging students in a virtual environment
It is difficult to build a rapport with students online.		
Challenges associated with building a sense of community between academics and students.		
Reciprocal care between academics and students regarding the challenges of the pandemic (i.e., students are aware of the challenges academics face with delivering virtually and balancing childcare, and academics are aware of the challenges students face with learning virtually).		
The perception that academics are teaching to a blank screen and are therefore unable to connect with and know their students.		
Recreating informal and social spaces when teaching online is challenging, and therefore, a sense of community amongst students is lacking.		
The lack of synergy between educators and students is perceived to be challenging to manage.		
Encouraging students to communicate within online sessions is more challenging than when delivering face-to-face.	Teaching in the dark: the challenges of knowing whether students are engaging and understanding the content	
A lack of feedback from students during sessions makes it challenging for academics to know whether they are understanding content, making it difficult to adapt sessions to the students' needs.		
Delivering to a blank screen makes it difficult to see if students are engaging with the content.		
The perception that academics are putting more time in and receiving less due to limited interactions with students.		
Uncertainty as to whether students are even watching the session (i.e., logging in to receive an attendance mark but not watching).		
Academics are concerned that students may be missing out on content due to a historical lack of engagement with the institutions' virtual learning environments when being taught face-to-face.		
Uncertainty in how to engage students online and whether they are engaged when being taught online.		
Uncertainty as to whether students are understanding content and able to apply the knowledge being taught.		
Concerns regarding equality for students based on their ability to access content, which could be determined by their background, cultural and social capital, ability to use IT, and virtual study spaces.	An uneven playing field: concerns regarding the accessibility of online learning for students with varying needs	
Concerns regarding the challenges of accessibility for disabled students and staff (in particula,r, those with hearing loss).		
Poor work–life balance.	When does the working day end? An imbalance in work–life integration	Work–life challenges experienced when delivering from home
The perception that working from home has made it difficult to separate the balance between work and life.		
A lack of separation between work and life.		
The transition period between home and work has gone.		
Feeling like you have all the time in the world, but at the same time, no time at all.		
No holidays to aim towards when working, making it harder to feel motivated to meet deadlines.	When there is little to look forward to: the implications of a lack of personal pleasures on motivation within work	
An inability to go places on the weekend makes it hard to look forward to during the working week, resulting in lower motivation.		
A shift in perception such that instead of looking forwards to engaging in fun activities on the weekend, you look forward to having something to do at work due to the inability to enjoy pleasures that you normally would on a weekend.		
It is difficult to have focus and look forward to time off when there are restrictions on which activities you can engage in during your time off.		
Less movement during the working day results in fewer positive feelings regarding oneself and one's quality of delivery.	Barriers to achievement: the perceived impact of teaching at home on the quality of delivery	
A lack of movement during teaching results in teaching experiences being less positive.		
Balancing work and personal stressors (i.e., partners, children) results in teaching experiences being less positive.		

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education sciences

Article

Research Performance: A View of Research Self-Efficacy, Interest, and Gender

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Abstract: There is great interest in promoting research in academic institutions and a need to understand the various factors influencing it. The main goals of this study are to investigate the factors that predict academic research outcomes and how gender and research authority (RA) support programs affect the relationship between research self-efficacy and research interest. The participants included 143 faculty members who completed a questionnaire, 19 of whom were interviewed. The results indicate that the faculty members' research interests and the RA's support significantly predicted academic research outcomes. A positive and significant correlation was found between research self-efficacy and research interest. Gender and RA support were found to significantly moderate this relationship. Research self-efficacy had almost no effect on research interest among female faculty members and among faculty members who had received support from the research authority. In contrast, among male faculty members and among those who did not receive support from the research authority, the higher the research self-efficacy, the higher the research interest. An analysis of faculty members' perceptions points to four factors that can advance research outcomes: support from the RA, mentoring, collaboration among researchers, and allotting time for research. Understanding the moderating role of gender is important to reveal the underlying mechanism of a gender gap in research interest and consequently in academic performance, considering the increased recognition that universities worldwide are male dominated and that women are underrepresented in senior positions in academia.

Keywords: academic performance; gender; research interest; research self-efficacy; research authority

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1. Introduction

Research is one of the key components of the work of academic institutions and is an important consideration in the funding [1–3] and professional development of faculty members [4]. Interest in improving the research performance of the higher education system is shared by many academic institutions around the world, but the theory and empirical capacity of research performance are not yet fully formed [5–8]. Various factors affect academic performance [3,6]. Bazeley [6] used an open-ended questionnaire among 295 academic teaching staff who were asked to give a description of their research. Based on a qualitative analysis, she suggested two preconditions for effective research performance training and experience. These provide an essential foundation for the skills required for high-level research, in addition to opportunities and resources including time, equipment, and funding. In addition, a conceptual model of the dimensions of research performance was extracted. Four dimensions were identified as research activities—engagement, task orientation, research practice, and intellectual process (analytic capacity and creative thinking). Two dimensions were identified as making the research visible—dissemination and collegial engagement.

Many academic institutions have established research authorities (RAs) with the aim of promoting academic research; however, few studies have examined the activity of these RAs. Croghan et al. [9] defined the essential services that RAs should provide: scientific mentorship and navigation, supervision and mentoring of research staff, protocol development/regulation, study coordination/data management, and innovative cutting-edge programs. Snyder et al. [10] proposed three indices for evaluating the effectiveness of an RA: efficiency in performing actions (measured by average times for responding to and handling relevant inquiries), researchers' satisfaction with service, and economic growth.

The initial aim of this study was to examine how RA support programs contribute to research productivity. The study's preliminary findings led to more in-depth research questions as part of the second stage of the study. Therefore, the literature review deals with various aspects that may influence research outcomes of faculty members, such as research interest, research self-efficacy, and gender.

1.1. Literature Review

1.1.1. Gender and Research Outcomes

Various studies have been conducted among higher education staff members regarding competitiveness, job insecurity, increased work demands, tenure-related demands, research and publication pressures, teaching loads, and opportunities for promotion [11–13]. Many of them have examined the effect of gender, in light of the increased recognition that universities worldwide are male dominated and that women are underrepresented in senior positions in academia [14–20]. Several explanations have been presented for women's underrepresentation in the senior ranks of academies, such as limited mentoring [21,22], a lack of supportive networks [23], and insufficient socialization into academia [24].

In an investigation of the relationship between research outcomes (scientific publications) and gender, Rørstad and Aksnes [25] found that female researchers had approximately 20 percent lower publication counts than men, although there were significant variations by field and academic position. Vasil [26] reported that men spent significantly more time on research activities and had a greater academic productivity than women. Aiston and Jung [27] found that academic women are publishing fewer journal articles and book chapters; however, familial responsibilities are not adversely affecting this situation.

The issue of gender in higher education has been explored from different perspectives of the patriarchy [28,29], male-dominated norms and practices [24], women's self-efficacy or self-agency [30,31], women's priorities in promoting their personal rather than professional lives [24,32], capabilities for promoting gender equality [33], and institutional rank progression structures for academic promotions [34]. The gender issue among female researchers in academia is complex and is dependent on many factors [27].

1.1.2. Research Interest and Research Self-Efficacy

Research outcomes depend on a wide range of emotional, cultural, organizational, and managerial factors. Productive research behaviour, which is measured mainly by a high number of publications, has been found to be positively related to the faculty member's level of research interest [35] and sense of confidence in their research abilities [36,37]. Several studies have indicated a relationship of research self-efficacy, interest in research, and research outcomes [30,38–41].

Self-efficacy refers to an individual's belief in their ability to perform certain tasks [42] and involves their cognitive processes (thinking like a scholar–researcher), behaviour choices (conducting research activities), and motivations [30]. Bandura [43] claims that self-efficacy is developed through the cognitive integration of four indications: enactive mastery (successes heighten perceived self-efficacy while repeated failures lower it), vicarious experience (seeing similar others perform successfully can raise self-efficacy expectations), verbal persuasion (encouraging and leading to sufficient effort to succeed), and emotional arousal (high arousal usually debilitates performance, people are therefore more inclined to expect success when they are not beset than if they are tense and unreasonably disturbed). Self-efficacy is a predictor of performance, due to its relationship with aspirations, commitment to goals, and persistence in continuing with the task [43–45]. Pajares [46] argued that behaviours are more effectively predicted by individuals' beliefs about their capabilities than by their actual capabilities.

Research self-efficacy predicts interest in conducting research [37,47]. Interest in research is grounded in the social-cognitive model suggested by Lent et al. [35] and depends on personal characteristics, environmental influences, research self-efficacy, and research outcome expectations. Personal characteristics such as gender and age affect interest in research directly and indirectly, through research self-efficacy, research outcome expectations, and environmental influences [30].

An examination of the role of gender in this respect based on two variables—research self-efficacy and interest in research—has not produced clear-cut conclusions [48]. For example, Wright and Holttum [49] did not find a significant relationship between gender and research self-efficacy or research interest but did corroborate previous research findings that research self-efficacy mediates the relationship between masculinity and the intention to do research [50]. Griffioen et al. [39] and Kerrigan and Hayes [51] also found no significant relationship between gender and research self-efficacy or research interest. In comparison, Vasil [26] reported significant differences between men and women in research self-efficacy beliefs, in favour of universities' male staff members.

In addition to the three variables presented above (gender, research interest, and research self-efficacy), we chose to examine the issue of research performance also in the context of three additional variables: faculty (Sciences/Social Sciences), main research method (quantitative/qualitative/mixed methods), and RAs' support. The choice of these variables is based on previous studies that found that they may also affect research performance. Wood [3], for example, claimed that the different research styles, processes, and techniques are the most important factors in explaining variations in research productivity. The type of research method (quantitative or qualitative) employed differs by discipline (natural sciences or social sciences and humanities). Wanner et al. [52] found an advantage for research productivity of researchers from the field of science. It is also important to consider previous findings of a correlation between gender and research method preference, with being women biased towards qualitative methods [49]. In the same vein, Grant et al. [53] found that the use of qualitative methods was significantly higher among women. As mentioned, the justification for examining RAs' contributions to research productivity stems from the lack of studies in this context and the definition of their roles in the promotion of research in the academic institution [9,10].

2. Materials and Method

2.1. Research Questions—First Stage of the Study

As stated, the initial aim of the study was to understand the role of the RA in promoting research among faculty members. The study was conducted with the approval of the research authority and the management of the college. In this context, two research questions were raised in the first stage of our study:

1. According to the views of faculty members, what could increase their research outcomes?
2. What are the factors that predict academic research outcomes?

2.2. Methodology

2.2.1. Research Tools

The number of publications, citation counts, doctoral students, and competitive research funds are common indicators for research productivity [54]. To answer the research questions, a combination of quantitative and qualitative tools was employed. The instruments included a close-ended questionnaire and semi-structured interviews. We used a four-part questionnaire. The first part was comprised of items on the participant's demographic data: gender (man/woman), age, seniority at the college, faculty (Science and Technology/Social Sciences and Humanities), institutional status (lecturer/adjunct), degree (Dr/Prof.), main research method (quantitative/qualitative/mixed methods), and whether the faculty member received RA support or not. The second part assessed research self-efficacy using eight statements that describe different research activities. The participants were asked to rate their level of confidence in performing each research activity on a scale of 0 (total insecurity) to 10 (total confidence). The statements were based on the works of Bieschke et al. [55], Forester et al. [56], and Pasupathy and Siwatu [48]. Examples of statements in this part of the questionnaire include "generate researchable questions" and "choose an appropriate research design". The Cronbach's alpha reliability was 0.894.

The third part of the questionnaire examined research interest; it was based on Kerrigan and Hayes [51] and Lambie et al. [30]. Nine statements were presented, and the participants were asked to rate their level of interest regarding each statement on a scale of 1 (lack of interest) to 5 (high level of interest). Examples of statements in this part of the questionnaire included "reading a research journal article" and "taking a statistics course". The Cronbach's alpha was 0.849. The fourth part of the questionnaire examined research outcomes. Participants were asked to report on their research products (participating in conferences, winning grants, publishing articles or books, and supervising of graduate students) in the last four years. This part was based on Pasupathy and Siwatu [48]. The variable of research outcomes was constructed as an average of the subjects' reports in this section. At the end of the questionnaire, the participants were asked if they would agree to be interviewed. Nineteen semi-structured interviews were conducted with participants who agreed. Each interview lasted about 45 min. The purpose of the interviews was to examine the participants' views regarding the factors that could influence their research outcomes. Participants were asked, for example, how do they perceive themselves as researchers? what are the ways in their opinion for professional development as researchers? What can promote such development? What can hinder? How can the research authority at the college support the professional development as researchers? Do they know the requirements for faculty promotion in the college? Do they think that changes are necessary and if so, why, and how? What are their research outcomes? What factors might contribute to an increase in their research outcomes?

Subjects who did not answer most of the questions (over 60%) were removed from the sample. The analysis was performed on all the items in the questionnaire (the highest frequency of missing was 22%), assuming that it is missing at random; therefore, the subjects were included in the sample and the analysis included empty cells in these cases.

2.2.2. Research Population

The research took place at a college in northern Israel with about 400 faculty members and about 3500 students. The college has two faculties: the Faculty of Science and Technology and the Faculty of Social Sciences and Humanities. The college management encourages research among faculty members through the activity of the research authority. A total of 143 faculty members (61% of the research population) completed the questionnaire. There were 52% men and 46% women (3 did not indicate gender). A total of 60% of the faculty members who participated in the study taught in the Faculty of Social Sciences and Humanities and 40% in the Faculty of Science and Technology. Regarding institutional status, 58% of the faculty members were lecturers and 32% were adjunct teachers (14 did not answer this question). A total of 75% held a PhD degree and 15% held a professor degree (15 did not reply to this question). A total of 40% of the faculty members indicated that the main research method they used was quantitative, 18% indicated a qualitative research method, and 27% indicated a mixed-method approach (20 did not reply to this question). The average seniority in the college of the participants was 9.85 years, with a standard deviation or 7.44, and a median of 9 years. The oldest faculty member had been teaching at the college for 35 years and the least senior had worked at the college for only 1 year. A total of 50% of the participants had not used the support of the RA in the last four years and 41% had (14 did not reply to this question). Fifteen percent of the faculty members indicated that they were mentoring another faculty member in research processes. The average age of the participants was 50.74 years, with a standard deviation of 10.03, and median of 50 years. The oldest faculty member was 72 years old and the youngest was 30 years old.

The interviews were held with 11 men and 8 women. The average seniority at the college of the interviewees was 10.61 years with a standard deviation of 6.18 years. A total of 4 participants taught in the Faculty of Science and Technology and 15 in the Faculty of Social Sciences and Humanities.

3. Results

3.1. First Stage of the Study

The findings are presented according to the research questions.

3.1.1. RQ#1: Faculty Members' Perceptions Regarding the Factors That Could Influence Their Research Outcomes

Analysis of the faculty members' answers regarding the factors that might contribute to increasing their research outcomes indicated four main factors: support of the RA, mentoring, collaboration among researchers, and allotting time for research.

Research Authority Support

Several actions by the RA and/or the college were mentioned as increasing the productivity of faculty members as researchers. These included internal grants and financial aid, research workshops, the provision of administrative services and information, and help with submitting proposals to external foundations.

The following examples demonstrate that offering grants was perceived as a factor that motivated faculty members to conduct research and submit proposals to external foundations:

> "Undoubtedly, I think that without this there would be nothing. It serves as an incentive. An internal call for research is less threatening than an external one. It encourages people to write, It's not an entire research proposal. It's much simpler and it helps people get started." (Interviewee 13)

> "I received grants [internal calls for papers] once or twice and that gave me confidence to submit research to the National Science Foundation (ISF)." (Interviewee 7)

> "These grants provide seed money for research so that you can examine probability and receive initial findings. You are then able to receive a significant research grant." (Interviewee 3)

According to these references, it is evident that the faculty members perceive the college's internal research grants to be a motivating and encouraging factor in carrying out research, both from a practical and even a psychological point of view. They receive initial findings and feel more confident to submit research proposals to external funds.

Faculty members noted that the process of submitting a request for a grant and receiving feedback constituted a learning process and helped them become better researchers:

> "You receive comments and you have to read them, even if they irritate you and you don't agree with them. You will gain from them and become a better researcher." (Interviewee 3)

One of the interviewees suggested dividing the budget for research grants differently, so that more applicants could receive help:

> "If it were possible to create a norm by which each researcher tries to utilise the amount of money that is available and calculate exactly how much they need, we could give what remains to others. I think that would be fair." (Interviewee 9)

The proposal for a fairer distribution indicates the desire of the researchers to promote all the researchers in the entire college and not just themselves personally.

The faculty members also perceived providing a budget and financial aid as an important means of promoting research activities:

> "In my experience, the college helps a lot. I didn't request everything that I wanted, but they gave a lot of money. The college offers a lot of possibilities. It's always possible to do more. I think that if you want to conduct a moderate-sized research project in the social sciences, you can do so with the money from the college. The natural sciences are a different matter." (Interviewee 15)

> "The budget enables us to attend conferences and present our research, attend research workshops, purchase equipment, and hire research assistants." (Interviewee 9)

These quotes indicate that faculty members acknowledge the college's efforts in supporting them in conducting research and publishing articles. In addition, it helps them to attend conferences and workshops and to enhance their research skills and professional growth. Interviewee 15 noted that, although the college offers a lot of possibilities, conducting research in natural sciences requires more funding than in social sciences.

Some of the interviewees were satisfied with the research workshops, as illustrated by the following:

> "The RA conducted two workshops. It also publishes data and offers incentives and support. We receive data about foundations and proposals from many universities abroad. We have an excellent RA." (Interviewee 14)

It seems that the faculty members perceived the workshops as useful and promoting their research skills and that they overall appreciate the incentives given by the RA and the information about foundations and proposals from universities abroad to support their academic promotion.

Another aspect that the interviewees noted was the offering of administrative services and information to the researchers and lecturers at the college:

> "I can't tell you whether we are being encouraged here or not. On the level of distributing information, anything that is connected to the college itself, even matters that are not connected to my field, are sent by email. There are constant updates about seminars and about local and international conferences." (Interviewee 6)

However, some of the faculty members felt that the response from the administration and information sharing was insufficient:

> "I was told there was a budget for bringing researchers from abroad. I don't know what to say. I don't have enough guidance in this area. I was told: 'Call the international relations department.' But I feel that this should be more than just an institution. Individuals shouldn't have to be the ones to call and make contact and try to gather information." (Interviewee 8)

It seems that the faculty members do not receive a supportive and detailed guidance regarding hosting researchers from abroad and expanding collaborations at an international level. They think it should not be their merely responsibility as individuals and they should be given more support. These references might indicate a broader concern in the institutional organizational culture.

The interviewees explained that faculty members helped them with approaching external research foundations in all matters pertaining to writing a budget for a research proposal. They expressed satisfaction with help regarding budgeting:

> "I always receive help from a member of the faculty who is a member of the RA. He goes over our division of budgets and makes changes according to his perception. His view is correct for dealing with a call for research." (Interviewee 12)

> "I think that from this standpoint we have no problem with the budget because there is a member of the faculty who is performing this job. During all the

> meetings I have attended, I have seen that he is perhaps one of the people who best understands budget management." (Interviewee 1)

However, in other matters associated with submitting requests to external foundations, some needs were not adequately met:

> "A system of technical support needs to be created here for writing research proposals, reading them, and ensuring that they are professional." (Interviewee 15)

> "When I want to submit a request to external research foundations, I feel that there is no one here who will help me. I need skilled staff that can provide organised information about all the European foundations, support editing and budget issues." (Interviewee 2)

These quotes indicate that faculty members do not receive adequate technical and professional support from the institution relating writing research proposals and requests to external research grants; it seems that there is a need for a system of technical support within the institution.

Mentoring

The interviewees mentioned additional actions that the RA and the college could take to help lecturers and researchers progress and develop. One of these recommendations was to create a system of mentoring, consultation, and guidance in the college. For example, experienced researchers could offer support and guidance to new or young researchers in the college:

> "I think that many people are occupied with their own matters and that mentoring would help. Senior lecturers should take newer lecturers under their wing. I think that would help." (Interviewee 8)

> "I'm in favour of beginning lecturers receiving a mentor from the same discipline who understands the subject." (Interviewee 14)

The above references highlight the significance of having a mentoring and guidance system in the college that will provide support and consultation services that are needed for researchers in their early stages of career development. These mentors will be able to help researchers both methodologically and in terms of fields of knowledge, ensuring a comprehensive and effective support system for all.

Collaboration between Researchers

Faculty members also recommended collaboration among researchers within and outside the college:

> "A college is a place where each of us is alone on an island and occupied with his or her own matters. Some of us succeed in connecting with others and some of us don't. The college doesn't provide opportunities for sharing common space. There is no day during which we conduct research, meet, or consult together. We come here to teach and then we leave, and we have little time for anything else." (Interviewee 9)

> "Perhaps the RA can create connections between researchers. This doesn't even have to be from within the college. They could also be from outside the college. They could create a database of researchers and create matches between people. That way we would have someone to approach and receive help in developing." (Interviewee 12)

It seems that the faculty members feel isolated and have a lack of opportunities for peer collaborations, since they are busy with their work and have little time for peer meetings and consultations. Interviewee 12 suggested the establishment of a data base of researchers in which scholars can find colleagues with the same research interests. This could help researchers to collaborate with their colleagues both within and outside the college and to promote their research productivity and enhance their professional development.

Allotting Time for Research

The faculty members also recommended allotting time to researchers for conducting research and decreasing their workload:

> "Time. The most significant thing would be if I had a sabbatical year every three, four, or five years and a budget that would enable me to be free to conduct research." (Interviewee 7)

The faculty members spoke about cutting down teaching hours that are assigned to lecturers and researchers at the college:

> "My entire research was conducted on a voluntary basis because the college allows lecturers who are conducting research to cut back their teaching hours, but at the most we are talking about 4 h out of 24." (Interviewee 3)

> "Decreasing teaching hours always helps, but it's a matter of money. Sometimes there is a deficit and sometimes there is more money to give. It varies." (Interviewee 14)

The above quotes illustrate the complex situation the faculty members are experiencing in their academic profession. They are overload with teaching hours and have limited time to conduct research. Nevertheless, the faculty members seem to understand the college's budget limitations. Overall, these statements indicate the barriers that researchers face when balancing their teaching and research commitments and highlight the need for the college to enact changes regarding teaching hours. This is particularly true for lecturers who are interested in carrying out research and for whom the teaching load is a significant limitation.

3.1.2. RQ#2: The Factors That Predict Academic Research Outcomes

Multiple linear regression was used to identify the factors that significantly predicted research outcomes. Table 1 presents the results.

Table 1. Regression analysis of variables as predictors of the research outcomes.

Variable	B	Std. Err.	β
Gender (male/female) (G)	−0.03	0.22	−0.01
Faculty (Sciences/Social Sciences) (F)	0.15	0.22	0.07
Main research method (quantitative/qualitative/mixed methods) (RM)	−0.20	0.11	−0.19
RA's support (yes/no) (RAS)	0.53	0.21	0.25 *
Research self-efficacy (RE)	0.04	0.09	0.04
Research interest (RI)	0.69	0.20	0.36 **

* $p = 0.015$, ** $p = 0.01$.

The overall regression was statistically significant, $R^2 = 26\%$, $F(6, 82) = 4.420$, $p = 0.001$. The fitted regression model was academic research outcome = $-1.944 - 0.01(G) + 0.07(F) - 0.19(RM) + 0.25(RAS) + 0.04(RE) + 0.36(RI)$. According to the results, research interest and use of research authority support significantly predicted academic research outcomes. A higher level of research interest and having received assistance from the research authority had a higher chance of greater research productivity.

According to the results, and contrary to our expectations, gender and research self-efficacy did not significantly predict research outcomes. These findings have led us to deepen our study and to examine in the second stage the relationship between the four variables: research self-efficacy, research interest, gender, and RA support.

3.2. Research Question—Second Stage of the Study

Although the findings of the first stage of the study showed that gender and research self-efficacy did not significantly predict research outcomes, we assumed that there is an indirect relationship through the variable of research interest. Previous studies have indicated a relationship between research self-efficacy and interest in research (e.g., [30,38,40]). The variables are also theoretically related through the social-cognitive model suggested by Lent et al. [35]. This led to the assumption that a positive correlation was expected between the two variables. According to Lent et al. [35] theory, personal characteristics, such as gender, affect interest in research directly and indirectly, through research self-efficacy [30]. This relationship, in addition to previous studies that have indicated a direct connection between research self-efficacy and gender (e.g., [26]), has led us to assume that gender can influence the relationship between research self-efficacy and research interest. In light of the lack of research on RAs' contribution to various aspects related to research (as claimed by Croghan et al. [9] and Snyder et al. [10]), we suggested investigating the research model shown in Figure 1. According to this research model we hypothesized that there is a positive correlation between research self-efficacy and research interest and that gender and RA support may moderate this relationship.

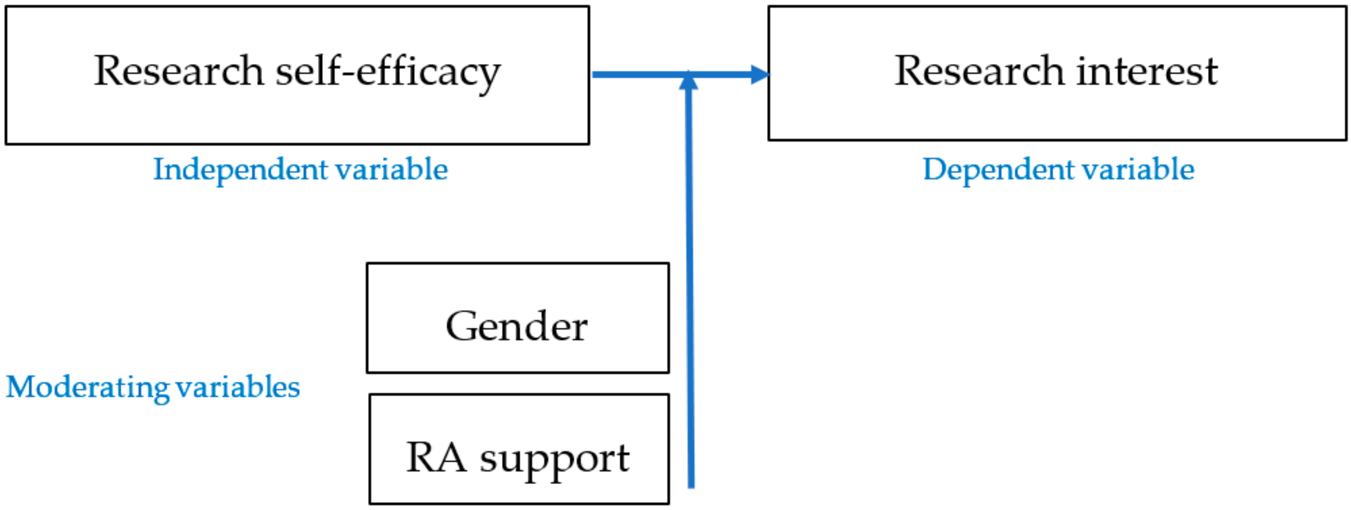

Figure 1. The research model.

A third research question was raised: what is the relationship between research self-efficacy and research interest, and how do gender and RA support affect this relationship? Further analysis of the questionnaire was performed to reply to this question.

Second Stage of the Study

RQ#3: The Relationship between Research Self-Efficacy and Research Interest and the Effect of Gender and Research Authority Support on this Relationship

The third research question explored the relationship between research self-efficacy and research interest, and of gender and RA support as moderating variables of this relationship. Table 2 presents the descriptive statistics and the correlations between all the research variables as a preliminary stage for the statistical examination of the moderating variables.

Table 2. Descriptive statistics and correlations between the study variables.

Variable	Mean	*SD*	1	2
1. Research self-efficacy	8.64	1.32	1	0.42 **
2. Research interest	4.09	0.68	-	-

** $p = 0.000$.

A significant moderate and positive correlation was found between research self-efficacy and research interest (r = 0.42). A similar correlation (r = 0.43) was found between research interest and research outcomes.

We performed the analysis using Hayes' [57] PROCESS macro in SPSS 25.0 to explore the moderation effect, where research self-efficacy was the independent variable and research interest was the dependent variable. Gender and RA support were found to significantly moderate the relationship between research self-efficacy and research interest. Table 3 presents the interactions between the study variables.

Table 3. Analysis of interactions between the study variables.

Variable	B	Std. Err.	β
Gender	0.05	0.11	0.04
Research self-efficacy	0.54	0.13	1.12 **
Gender * Research self-efficacy	−0.23	0.09	−0.74 *
RA support	−0.11	0.11	−0.09
Research self-efficacy	−0.23	0.12	−0.49
Research authority support * Research self-efficacy	0.32	0.09	0.97 **

* $p = 0.01$, ** $p = 0.000$.

As illustrated in Figure 2a,b, research self-efficacy had almost no effect on research interest among female faculty members and among faculty members who received support from the research authority. In contrast, among male faculty members and among faculty members who did not receive support from the research authority research interest was higher when research self-efficacy was higher. Gender (in the case of men) and lack of support of the RA strengthened the relationship between research self-efficacy and research interest. Figure 2a,b present the results.

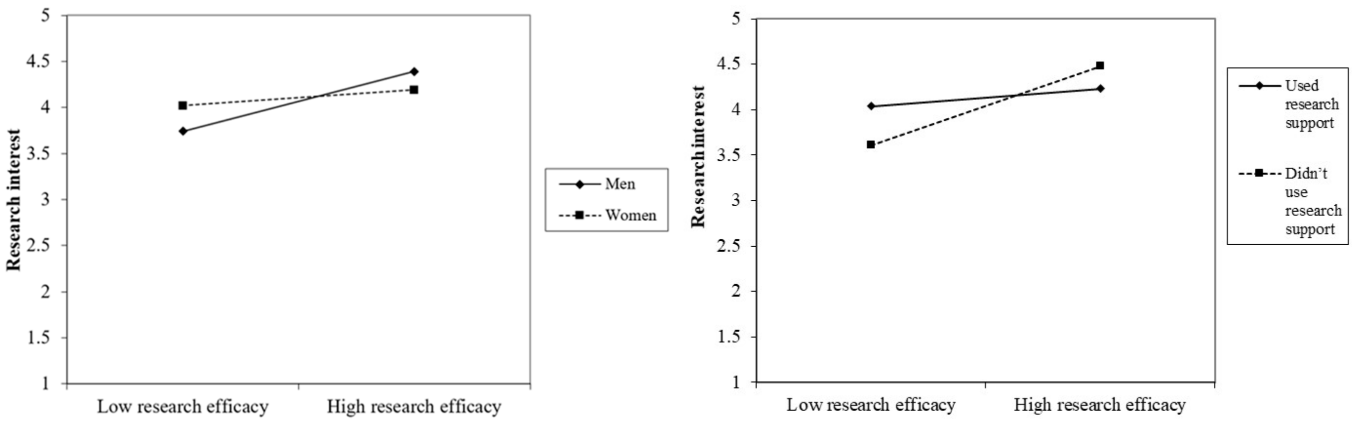

Figure 2. (**a**) Gender as a moderating variable and (**b**) research authority support as a moderating variable.

4. Discussion

The main goals of this study were to understand the faculty members' perceptions about the factors that might influence their research outcomes, to investigate the factors that predict research outcomes, and to explore how gender and support actions of the RA moderate the relationship between research self-efficacy and research interest. A close-ended questionnaire and semi-structured interviews were used.

Two variables significantly predicted the academic research outcomes according to the results in this study: research interest and use of research authority support. A faculty member who had a high level of research interest and assistance from the research authority was found to have a better chance of greater research outcomes.

The present findings indicated that gender and research self-efficacy did not significantly predict research outcomes, but that research self-efficacy was significantly correlated with research interest, which significantly predicted research outcomes. Previous studies also found a positive relationship between research self-efficacy, interest, and research outcomes [30,39,40]. The significant and positive connection between research self-efficacy and interest can be explained using the social-cognitive model suggested by Lent et al. [35].

One of the interesting findings of the present study concerns the moderation of the relationship between research self-efficacy and interest by the gender variable. Gender significantly moderated this relationship and in the case of male participants, strengthened it. We found no previous studies on the moderating effect of gender on the relationship between research self-efficacy and interest. However, in a broader search, we found studies that examined the effect of gender on the relationship between similar measures of sense of confidence and interest in different areas, such as entrepreneurship. Shinnar et al. [58] found that gender had a significant moderating effect on the relationship between a perceived lack of support barriers and entrepreneurial intention (in the United States and Belgium, a stronger negative relationship was found among men than among women). However, they did not find a significant effect of gender on the relationship between the perceived fear-of-failure barrier and entrepreneurial intention.

Psychological and social factors might explain the intervention of the gender variable in the relationship between research self-efficacy and research interest. Previous studies (e.g., [59]) indicated that factors such as marriage, children, and domestic workload were related to the productivity of women in research. Women may recognise the influence of these family factors and are therefore less likely to form a relationship between their research interests and their sense of self-efficacy. In comparison, among men, who have no similar recognition of family commitments, a low sense of research self-efficacy lowers interest in the field of research and thus diminishes research productivity. This explanation is in line with the findings of Monroe et al. [60], who found that women in academia did not judge balancing work and childcare as relevant to their academic institute.

Both the quantitative and the qualitative findings of our research indicated that RA support helps to promote research outcomes. Faculty members who used the research authority support programs were more likely to have better research outcomes. In addition, a lack of RA support strengthened the relationship between research self-efficacy and research interest. An analysis of faculty members' perceptions indicated several RA actions that can support research productivity: internal grants, offering budgets and financial aid, offering research workshops, providing administrative services and information, and helping with the submitting of proposals to external foundations. Previous studies found that academic support programs contributed to the advancement of research by faculty members (e.g., [6,61–63]). Wood [3] and Ito and Brotheridge [64] also emphasised the availability of funding, such as research grants, as an important factor influencing research activities.

Our analysis of the interviews in the present study indicated three other factors that might increase research productivity: mentoring, collaboration between researchers, and allotting time for research. The interviewees highlighted the importance of a mentoring system that accompanies them and provides them with the consultation services needed for researchers in the early stages of their academic development. In addition, they noted the need to establish a data base of researchers for scholarly collaborations both within and without the college. These findings reinforce those from previous studies. Collaboration with peers and mentoring with experienced researchers were found to be crucial elements in providing a supportive climate for researchers [3,61,63,65]. Regarding the third factor, the allotting of time for research, faculty members described the challenges they faced regarding the need to balance their teaching hours with their roles as researchers. The time dedicated to conducting research is limited due to their being overloaded with teaching hours. They suggested that the college will perform changes and reduce their teaching hours. These results also support Wood's [3] claim that heavy teaching loads limit the ability of faculty members to conduct quality research. This is consistent with Ito and Brotheridge's [64] finding that the amount of time that faculty members invested in research activities predicted their level of research productivity.

One of the main strengths of this study is its combination of quantitative and qualitative tools. Its limitation is that it has focused on only one academic institution and with a relatively low number of faculty members; this may make it difficult to generalise the findings. It would be important and interesting to expand the research to include a greater number of faculty members and of different academic institutions. Nevertheless, this study is of great importance. There is widespread agreement that more attention should be paid to the development of researchers throughout their careers [66,67]. In response, academic institutions are focusing their efforts on building research capacity and capability [65]. There is an increasing emphasis on the measurement and accountability of academic research activity [7,68]. This highlights the importance of the current research, especially considering Ito and Brotheridge's [64] claim that very little research has explored the strategies employed by faculty members to improve their research productivity. Despite the extensive research conducted on the research self-efficacy and research interest of faculty members, there has been only limited investigation of whether the relationship between these variables differs according to gender. Understanding the moderating role of gender is important in revealing the underlying mechanism of a gender gap in research interest and consequently in academic performance. The present findings emphasise the importance of academic support programs in advancing research productivity and the need to consider different components when designing intervention programs for both men and women.

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Students' Epistemological Framings When Solving an Area Problem of a Degenerate Triangle: The Influence of Presence and Absence of a Drawing

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Abstract: This study explores the epistemological framings of undergraduate students when solving an area problem of a degenerate triangle, without or with a triangle drawing. Through mixed research with a triangulation design, the resolution processes and responses of students were analyzed. The aim was to analyze how students' epistemological framing changes during the problem-solving process depending on whether the task contains the drawing of the triangle or not. Quantitative results show significant differences between students who solve the problem without a triangle drawing and those who do. Qualitative results evidence that students who solved the problem with the drawing established an initial epistemological framing that contained an "obvious fact": the non-zero area of the triangle. They hardly modified this epistemological framing during the solving process, forcing the response to be a positive number. In contrast, students who solved the problem without the drawing easily modified their initial epistemological framing by observing that the area of the triangle was zero. Students' perceptions of the level of difficulty of the problem are discussed, too.

Keywords: degenerate triangle; impossible triangle; epistemological framing

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1. Introduction

Triangles are the simplest form of polygons, and their basic geometrical properties have been known for many centuries. Heron (10–70 d. C.) knew how to calculate the area of the triangle with side lengths 13, 14, and 15 in two different ways [1,2]. One way was to find out that the height on side 14 is 12, giving the area a value of 84. The other way was to use an algorithm, now known as "Heron's formula", which can be applied when the lengths of the triangle sides are known as:

$$Area = \sqrt{s(s-a)(s-b)(s-c)}$$

where $s = \frac{a+b+c}{2}$, a, b, and c are the lengths of the triangle sides.

In mathematics at school, students are supposed to learn: (a) which lengths can or cannot form the sides of a triangle [3]; (b) how to calculate the area of different kinds of triangles [4]; and (c) how to calculate the angles of a triangle if their side lengths are given [5,6]. The first objective is learned by students if they comprehend and know how to apply in different tasks the so-called "third side rule": The sum of any two sides of a triangle must be longer than the third side. Combining the first objective with the third objective leads to a classification of triangles into three types: regular triangles, degenerate triangles, and impossible triangles.

Fisher et al. [5] gave examples of these triangle types, asking students to use the "Law of cosines" to find all angles of the triangles with the following side lengths: (a) 2, 4, and 5; (b) 2, 3, and 5; (c) 2, 3, and 6. It turns out that the first triangle has angles of 22°, 108°, and

50°, making it a "common triangle". The second triangle should have two zero angles and one angle equal to 180°, making it a "degenerate triangle". The third triangle would not have real angles, being an "impossible triangle".

Applying Heron's formula to these examples, one finds additional characteristics: the area of the "common triangle" is a positive number (square root from 14.4375 or, approximately, 3.7997); the area of the "degenerate triangle" is zero; and the area of the "impossible triangle" is an imaginary number (square root from 24.0625 or, approximately, 4.9i (the number 4.9i is a complex number, more precisely a purely imaginary number, where $i = \sqrt{-1}$)).

In the literature, we can find examples where students are asked to calculate the angles of degenerate or impossible triangles. For example, in Barton [6], the degenerate triangle of sides lengths 7, 9, and 16 and the impossible triangle of sides lengths 17, 29, and 48 are provided; in Foerster [7], the impossible triangle with sides lengths 3, 5, and 10; and in Carter [8], the impossible triangle of sides lengths 5, 12, and 18 is provided.

Martin Gardner also used the notion of a "degenerate triangle" with zero area in his answers to two corresponding problems. The first example is shown in the following dialog [9] (p. 17):

> Which has the larger area? A triangle with sides of three, four, five, or a triangle with sides of 300, 400, and 700?
>
> The second one, naturally.
>
> Wrong!... The second triangle is degenerate. It's a straight line. Its area is zero.

The second example is shown in Figure 1 [10] (p. 102).

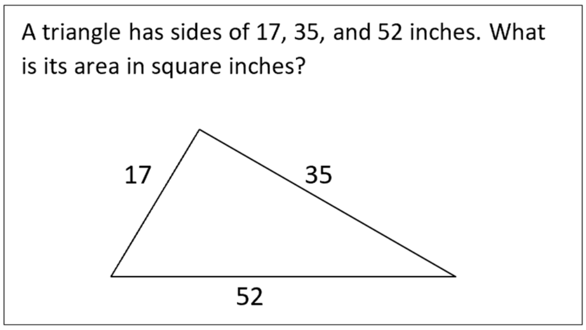


Figure 1. Figure adapted from Gardner [10] (p. 102).

Since we have used this problem in our study, it is important to point out that Gardner [10] has emphasized that these problems are short and easy, but each of them contains a funny twist that gives an unexpected turn to the answer. Gardner justifies the inclusion of these problems as follows: "A truly creative mathematician of scientist must have a mind that is constantly on the alert for surprising, off-beat angles" [10] (p. 100).

Gardner's answer to the problem in question is as follows [10] (p. 108): "A 'triangle' with the sides given would be a straight line (mathematicians sometimes call this a "degenerate triangle"), so it would have no area at all. This result shows that the students' perception of the connections between two problem parts is not a simple "attention" process but rather depends on the activation of adequate or inadequate knowledge or conceptual and procedural resources.

It is important that students become familiar with this type of problem in order to learn what degenerate figures are all about and that it is a mistake to draw them as if they were ordinary figures, because this type of figure is often found in the problems that are posed in textbooks [11–15] and teachers often do not recognize them either [16]. It would be very beneficial if these degenerate figures were easily recognized by teachers, appearing more in everyday geometry lessons and serving as an opportunity for learning and reflection.

An appropriate conceptual perspective from which to examine the process of solving this type of problem is the "resource framework", in particular the "epistemological framing". The resource framework is a model based on previous work in sociology by Goffman [17] and cognitive science by Minsky [18] and Schank [19]. It has been used in studies in science education [20] and specifically in engineering education [21], physics teaching [22,23], and mathematics education [24–26]. We will explain these concepts in detail below.

Thinking and learning are enormously complex processes. Thought is dynamic, with fragments of knowledge being freely associated and appearing in ways that may depend heavily on the individual's perception of the context and environment [21].

A particular theoretical way of thinking about student thinking and learning is the resource framework. It is a framework rather than a theory because it provides ontologies (classes of structural elements and the way they behave) and allows for a variety of possible structures and interactions built from these elements [23].

In phenomenological terms, by frame, we mean a set of expectations that an individual has of the situation in which he finds himself and that affect what he notices and how he intends to act. It is a person's framing of a situation, which can have many aspects, including social ("Who do I expect to interact with here and how?"), affective ("How do I expect to feel about this?"), epistemological ("What do I hope to do to answer questions and construct new knowledge?"), and others [27].

The basic ontology of the resource framework is that of an associative network based on the well-established metaphor of neurons in the brain. Everything that individuals have learned—a thought or the perception of a particular object—is stored in the state of a group of neurons, specifically in the strength of the synaptic connections of that specific group of neurons [21]. These groups of neurons can be considered a unit from the point of view of perception and functionality of the thinker. We refer to the cognitive elements of each group of neurons as a resource [27].

Just as the activation of one group of neurons leads to the activation of other groups of associated neurons, thoughts are represented as resources or groups of resources with strong associations that are not isolated, as one resource or group of resources leads to the activation of other resources [23].

As Bing and Redish [23] explain, this enables the creation of networks of higher-level structures that are perceived as unified by the user. This interconnection can occur at many levels and can be narrow or loose. They are narrow when they almost always manifest together, e.g., when we hear the word "cat" and the associated image of that feline appears in our mind; and loose when they are not so closely connected, e.g., when we can hear an orchestral performance as a whole or individually of a particular instrument. It is an extremely dynamic process, as associations between resources and groups of resources are activated and inhibited depending on the context.

Analyzing thinking in terms of associated resources or groups of resources leads us to suggest that students construct alternative associative pathways when misconceptions are treated as unary and instruction focuses on replacing these misconceptions with correct ones [21].

The resource framework also has a control structure. Control refers to the process by which certain resources are selected for activation rather than other resources that may be relevant [22]. From the wealth of information that reaches individuals and given their limited attentional and processing resources, they develop schemas that determine where they focus most of their attention, which parts of their memory and long-term skills they activate and apply, and which they suppress [23]. This control structure is highly context-dependent and controls which resources we make available under certain circumstances [21].

Following the structure proposed by Bing and Redish [23], epistemological resources are a component of the control structure of the model. They can be thought of as a package of information that, when activated, leads the person to interpret the knowledge in question from a particular perspective and controls which conceptual resources are used. They are a variety of resources that are used to build new knowledge and solve problems [22]. Epistemological resources, like other resources, are dynamic; they can be turned on and off during the course of a cognitive activity [23].

The process of reducing all epistemological and conceptual options to a manageable size that can be considered by the individual is called an epistemological frame [22]. Bing and Redish [23] explain it as a student's perception or judgment of the kind of knowledge that is appropriate to apply in a given situation.

The difference between a framework and a framing from MacLachlan and Reid's perspective [28] is that a framework is an individual's interpretation of "what is going on here?" and the form of gerund framing emphasizes interpretation as an ongoing process. An analysis in terms of epistemological framing focuses on the moment-to-moment changes observed in students' reasoning, as their interpretation of the task and the knowledge in question may change [23], for example, when a topic is discussed in class or a task is solved.

Finally, Felicity's condition is the tacit premise naturally adopted by an individual that incoming information, whether spoken, read, observed, and so on, comes from a rational source and depends on the individual's attempt to contextualize and interpret that incoming information [23].

In this study, we want to investigate how students deal with a verbal problem that contains an incorrect figure and how this differs from students who solve the verbal problem without such a figure. We ask how the figure affects students' epistemological framing when they are confronted with these situations and how it affects or does not affect their resolution processes.

For this reason, our research question in this paper is: How does students' epistemological framing change during the problem resolution process depending on whether the verbal problem contains the triangle drawing or not? The aim is to analyze how students' epistemological framing changes during the problem resolution process depending on whether the verbal problem contains the drawing of the triangle or not. The results will allow us to better understand how students deal epistemologically with ill-posed problems.

The hypothesis is that students who solve the verbal problem without the triangle drawing will perform better than students who solve the verbal problem with the triangle drawing.

2. A Brief Review of Problem Statements Involving Uncommon Triangles

The problems of degenerate or impossible triangles have been studied for a long time. In the first case of degenerate triangles, we can establish that, as far as we know, the first author to use a degenerate triangle in a mathematics textbook was the Italian mathematician Lorenzo Forestani in 1603 [29] (pp. 285–285A) as follows:

> And saying, it is the triangle A.B.C. with the base B.C. which is 20 "canna" and A.B. of 12 "canna", and A.C. of 8 "canna", it is asked how much is the surface [i.e., area]. You should know, that if the side A.B. is summed with the side A.C., and their sum is not longer than the base B.C., this question cannot be answered, however similar questions might be given to people with low knowledge.

The problem was complemented by the author with a drawing like Figure 2.

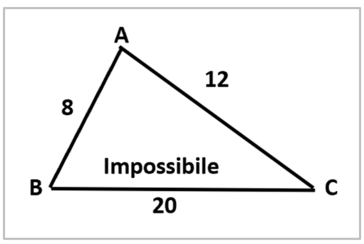


Figure 2. Drawing adapted from Forestani's illustration [28].

According to the terminology introduced above, the triangle presented by Forestani is not impossible but a degenerate one. As Forestani stated the problem, he did not pay too much attention to the drawing details. The text says that AB is equal to 12, but in the drawing, it is 8. Similarly, the text says the side AC is 8, but in the drawing, it is 12. This error was not corrected even in the revised edition, published in the year 1682 [30].

Another interesting problem, related to a triangle that becomes degenerate when two of its sides are doubled, was given to high school students in an Annual Contest organized by the Mathematical Association of America in 1961 [31] (p. 10):

> In triangle ABC, AB = 12, AC = 7, and BC = 10. If sides AB and AC are doubled while BC remains the same, then: (A) the area is doubled, (B) the altitude is doubled, (C) the area is four time the original area, (D) the median is unchanged, (E) the area of the triangle is 0.

A special kind of impossible triangle is one that has a supposed element that contradicts its basic characteristics. An example is the triangle in the following problem: "Find the area of the right-angled triangle if its hypotenuse is 10 cm and the height dropped on the hypotenuse is 6 cm" [32] (p. 3). This triangle is impossible because the maximum height on the 10 cm hypotenuse of a right-angle triangle is 5 cm.

In the same way, questions related to the area of degenerate triangles appear often in puzzle books. Table 1 brings three examples in which the sought answer is "zero", with or without an argument. The first two examples show a rather common phenomenon of formulating a new problem with only minimal changes.

Table 1. Three puzzles related to the area of degenerate triangles.

Puzzle	Authors' Answer
"A triangle has sides of 17, 42, and 59 inches. What is its area?" [33] (p. 66).	"Since 17 + 42 = 59, this is a very skinny triangle. Its area is zero" [33] (p. 187).
"A triangle has sides 17 cm, 42 cm, and 59 cm. Find its area" [34] (p. 26).	"Since 17 + 42 = 59, what results is a very skinny triangle. Its area is zero" [34] (p. 184).
"Which triangle is larger—one with sides measuring 200, 300, and 400 cm or one with sides measuring 300, 400, and 700 cm?" [35] (p. 171).	"The first triangle is larger-one with sides measuring 200, 300, and 400 cm. The triangle with sides measuring 300, 400, and 700 cm has an area of zero!" [35] (p. 273).

In the second case regarding impossible triangles, in contemporary mathematics textbooks, it is observed, in practical activities, how the triangle inequality is learned through this type of problem. For example, Tanton [36] (p. 26) provides the following problems: "(a) Draw a triangle with sides 6 inches, 3 inches, and 2 inches, and (b) Draw a triangle with sides 67 inches, 23 inches, and 95 inches".

Some suggested problems have a less clear learning path and gain for example, in Francis [37] (p. 9), the following problem is established: "The sides of a triangle measure 3, 4, and 8. Find the perimeter and the area of this triangle". Although the author states that the problem "relates to the triangle-inequality and the assertion that a straight line is the shortest path between two points" (p. 9), it is quite uncertain what result students would give for the area of the triangle.

For Nitsche, a degenerate triangle is one "whose vertices lie on a straight line and whose area is zero" [38] (p. 202). A similar definition is given by Pogonowski more recently [39] (p. 79): "A degenerate triangle is one with collinear vertices and zero area." O'Rourke uses the same elements to define a degenerate triangle [40] (p. 148): "If you collapse a triangle so that one angle becomes 180° and the other two 0°, the resulting shape (which would appear visually as a line segment) can be considered a zero-area degenerate triangle."

Some authors give both answers ("the area is zero" or "the triangle does not exist"). MacHale is one of the advocates of two answers for the problem related to the area of a degenerate triangle. In 2006, his problem had the formulation [41] (p. 29): "What is the area of a triangle whose sides measure three meters, four meters and seven meters?" The answer was [41] (p. 72): "Its area is zero (or there is no such triangle)."

In 2015, the problem formulation differed in numbers and units, as established by Sloan and MacHale [42] (p. 7): "What is the area of a triangle whose sides measure 400 feet, 700 feet, and 300 feet? Two-answer approach was much more elaborated [42] (p. 48):

> There are really two answers to this problem, but they come to pretty same thing. Sticklers in mathematics would say there is no such triangle because the sum of the lengths on any two side of a triangle must be greater than the length of the third side, and here 700 = 400 + 300. Less fussy people would say that the area of the triangle is zero because it has collapsed to a line segment. You can take your choice.

In his extensive psychological research project on the mathematical abilities of schoolchildren, Krutetskii [43] used impossible triangles in some tasks in the area of so-called "unrealistic problems". These are the problems "whose numerical facts make the problem meaningless" [43] (p. 132). Two examples were: "The perimeter of a right triangle is equal to 3.72 m. Two of its sides are 1.24 m each. Find the third side" [43] (p. 132). And "What is the area of an isosceles right triangle with leg equal to 5a cm and hypotenuse equal to 12a cm?" [43] (p. 133). Krutetskii did not report on the performance of the children tested in solving these "unrealistic problems".

3. Method

3.1. Research Focus

The research conducted in this paper was a mixed-methods study with a triangulation design, i.e., the researcher uses quantitative and qualitative methods to investigate the same phenomenon and determine whether the two perspectives converge to a unified understanding of the research problem [44]. The qualitative part consisted of a content analysis of the students' written productions. The quantitative part dealt with an experimental design with two groups, posttest only, in which Fraenkel et al. [44] explain that there are two groups, both randomly assigned. One group receives the experimental treatment, the other does not, and both groups are then subjected to a posttest.

3.2. Population and Sample

The population consisted of first-year students at the Facultad de Ciencias de la Electrónica of the Benemérita Universidad Autónoma de Puebla, in Mexico. The experimental and control groups were determined by two-stage cluster random sampling. In the first stage, four groups were randomly selected from a total of 22 groups in the population. In the second stage, each of these four groups was again randomly divided into two subgroups. The experimental group consisted of students belonging to the union of half of the subgroups, and the control group consisted of the union of the other half of the subgroups. The experimental group of students solved the problem without the triangle drawing (hereafter referred to as "Group A"), and the control group solved the problem with the triangle drawing (hereafter referred to as "Group B"). Group A consisted of 37 students with an average age of 19.30 years, with the highest age being 26 years and eight months and the lowest age being 18 years (SD 1.41). Group B consisted of 41 students with an average age of 19.33 years, a maximum age of 21 years and 9 months, and a minimum age of 18 years (SD 0.94).

3.3. Instrument

The data collection instrument consisted of Gardner's degenerate triangle problem [10] in two versions, with the drawing of the triangle (see Figure 1) and without it. In addition, in both versions of the instrument, students were asked to:

(a) Describe verbally, without using a formula, the procedure you will use;

(b) Execute the plan mathematically and state the solution; and, once the problem is solved;
(c) Rate the difficulty of the task, with one option to choose from: *very difficult, difficult, normal, easy, and very easy*.

3.4. Data Collection and Analysis Procedure

The data collection procedure was carried out as follows: The experimental group was asked to solve the task without the triangle drawing (Figure 1), and the control group was asked to solve the task with the triangle drawing. The time required to solve the task was one hour.

The data analysis was carried out as follows: First, the qualitative analysis was carried out, followed by the quantitative analysis. The qualitative analysis was inductive. First, the students' responses were classified according to the type of solution method. Then, the solution processes of each type were analyzed in detail, both for the students who solved the problem with the drawing of the triangle and for those who solved it without it. As a result of the analysis, two categories were formed: students who had changed their epistemological framing during the solution process and students who had not. Finally, the quantitative study was conducted with a hypothesis test on the students' performance in solving the problem. The analysis was first conducted by one of the researchers and then reviewed by the other investigator to ensure the objectivity of the analysis. The agreement rate was approximately 90%.

4. Results and Analysis

The analysis of the results is presented in this order: first the quantitative results, then the qualitative analysis. We refer to the students from group A as A1, A2, . . ., A37, and the students from group B as B1, B2, . . ., B41. "The area of the triangle is zero" was scored as the correct answer.

4.1. Quantitative Analysis

As for the overall results, Table 2 shows the percentage of correct and incorrect answers in each group. The group of students who solved the problem without the triangle drawing (group A) had a better performance than the group who solved the problem with it (group B). First, it was found that the presence of the triangle drawing influenced the solution processes of the students in group B as they tried to obtain a non-zero area value. In contrast, the students in Group A, who solved the problem without drawing the triangle, had more freedom to reason with the data and, of course, to realize that it was not possible to obtain a triangle with these side lengths.

Table 2. Percentages of correct and incorrect answers in each group.

	Group A (No Triangle)	Group B (With Triangle)
Correct answers	67.6%	43.9%
Incorrect answers	32.4%	56.1%

In order to find out whether these results show significant differences, a hypothesis test for two independent proportions was carried out. At a significance level of $\alpha = 0.05$, we obtain a test statistic $z = 2.1$ and a p-value of 0.02. Therefore, conclude that there is sufficient evidence to support the claim that the proportion of correct answers to the task without the triangle drawing is significantly higher than the proportion of correct answers to the task with the triangle drawing.

As far as the solution strategies chosen by the students are concerned, Table 3 shows the most common.

Table 3. Solution strategies used by students to solve the problem.

Resolution Strategy	Group A (No Triangle)	Group B (With Triangle)
Heron's formula	43.2%	39%
Triangle inequality	32.4%	22%
Pythagoras theorem	8.1%	22%
Trigonometric ratios	0%	7.3%
Area formula	8.1%	7.3%
Other	8.1%	2.4%

In both groups, the solution strategy with the highest incidence was Heron's formula.

If we look closely at the specific results of the students' application of this formula, we see that the students in group A (without the triangle drawing) had more correct answers (81.8%) than incorrect answers (18.2%). For the students in group B (with a triangle drawing), however, the result was the opposite: 28.6% correct answers and 71.4% incorrect answers.

Regarding the students' perception of the difficulty of the task, the frequency obtained by each group is shown in Table 4. We first noted that the students in group A had higher percentages in regular and difficult categories, namely 86.5% in both categories, while group B obtained 65.9% in the same categories. It follows that the students in group A perceived the difficulty of the task as greater but ended up with more correct answers. In group B, on the other hand, the percentage was lower, but more students answered incorrectly. Note that 12.2% of the students in group B rated the problem as *easy* and 17.1% did not answer, which was not the case in group A.

Table 4. Frequency by difficulty level of the problem.

	Group A (Without Triangle Drawing)	Group B (With Triangle Drawing)
Very difficult	2.7%	4.9%
Difficult	40.5%	29.3%
Regular	45.9%	36.6%
Easy	5.4%	12.2%
Very easy	5.4%	0%
Unanswered	0%	17.1%

4.2. Qualitative Analysis

The results of the qualitative analysis of the students who solved the problem with the Heron formula are as follows: The analysis showed that the students who solved the task without drawing the triangle readily accepted the arithmetic result equal to zero, but the students who solved the task with drawing the triangle did not, forcing a non-zero result. Figure 3 shows the performance of students A9 and A14 from group A as an example. These students established an initial epistemological framing that contained no figure. The epistemological resource associated with the solution method of Heron's formula allowed them to develop a fluid and unchanging solution process. In this way, it is interpreted that they did not change their initial epistemological framing.

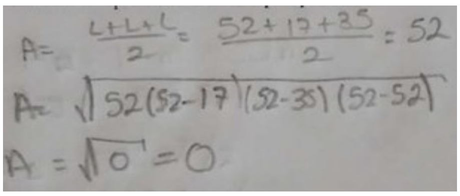
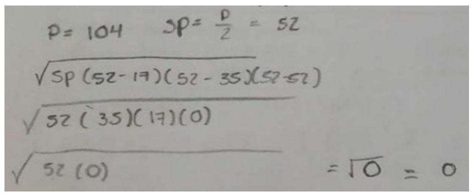
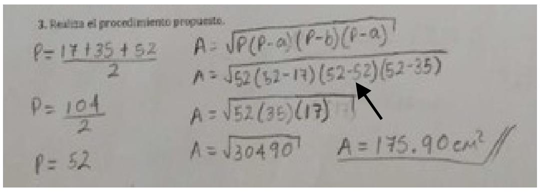
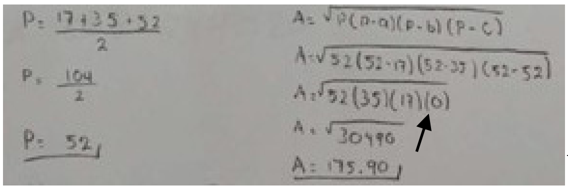

A9

A14

Figure 3. Correct procedures of two students in Group A.

In contrast, the students in group B with the triangle drawing mostly made the same math error, as can be seen in Figure 4. In the case of student B6, he eliminates the factor (52–52) to obtain a result that is not zero. In the case of student B22, he ignores the factor zero in the next step, even though he already had it. These students created an initial epistemological framing that includes the figure. In other words, they recognized that they had to find an area value greater than zero. By applying the epistemological resource of Heron's formula method, most developed a resolution process with the error of omitting a zero factor because they must obtain a non-zero result. In this way, it is interpreted that they could not change their initial epistemological framing by providing an erroneous result.



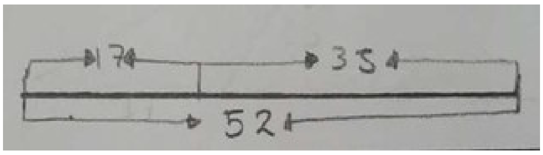
B6



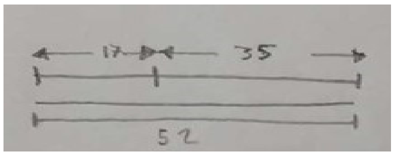
B22

Figure 4. Incorrect procedures of two students in Group B.

Another solution strategy that was used more frequently in both groups was triangular inequality, with a frequency of 32.4% in group A and 22% in group B. In this strategy, the students added the value of the two smaller sides of the triangle with lengths 17 and 35 to obtain the length of the third side, 52, from which they concluded that the triangle could not be formed. Figure 5 shows the graph of one student from each group, both with correct results and almost the same drawing. Of note is the change in the epistemological framing of the students in Group B, who ignore the triangle drawing in the task and conclude that the triangle is impossible. These Group B students changed their initial epistemological framing during the solution process. Despite the figure in the problem, they recognized that the triangle had been reduced to a line and that the triangle had degenerated. This result suggests that some students may change their initial epistemological framing during the solution process, even if it is only in a few cases.



A15

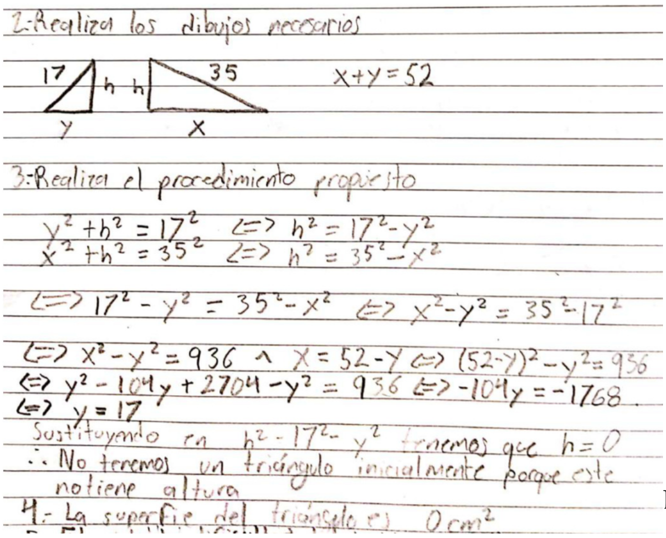


B16

Figure 5. Graphical representation of a student from each group in the triangle inequality strategy.

The Pythagorean Theorem strategy was used more frequently by students in group B (22%) than by those in group A (8.1%). We interpreted that this higher frequency in group B was due to the presence of the figure. We interpret that the students of Group B, who had the figure of the triangle in the presentation of the problem, were able to activate more easily the epistemological resource of the method of Pythagoras' theorem due to their initial epistemological framing. This situation did not occur in the group of students who did not have a triangle drawing.

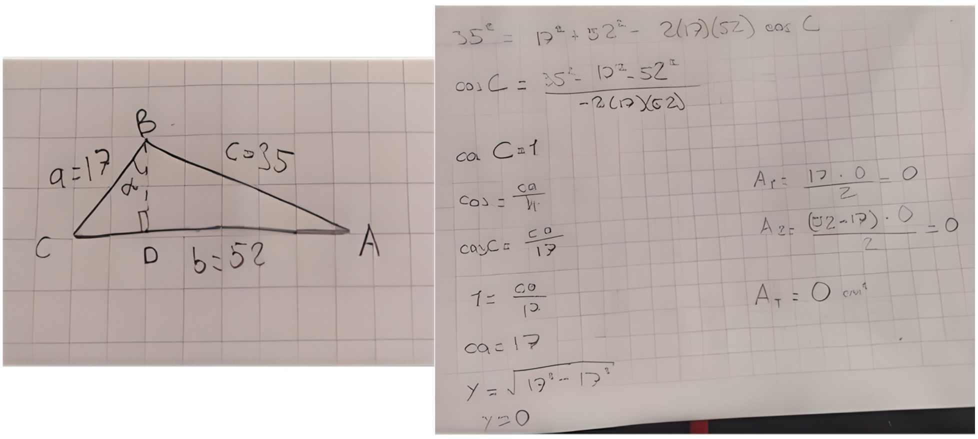
Of all the students in both groups who used the Pythagorean Theorem strategy, only one student from Group B developed the correct procedure, as can be seen in Figure 6. The student performs the whole procedure to draw the correct conclusion: "We do not have a triangle to begin with because it has no height [. . .] The surface area of the triangle is 0 cm^2". This student has a first epistemological framing with the triangular figure. He realized the mathematical procedure with this figure, and during the process, he changed his epistemological framing to accept that the triangle does not exist. In this way, he changed his initial epistemological framing to one that admitted that the triangle does not exist. Furthermore, this student classifies the problem as easy and trusts his solution.



B4

Figure 6. A student's procedure when using the strategy of the Pythagorean theorem.

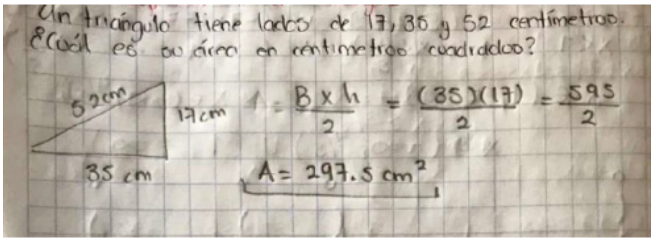
Very few students chose trigonometric ratios or the usual area formula as a solution strategy. Students in both groups arrived at incorrect results, with the exception of one student from Group B who correctly applied the cosine law and trigonometric ratios and obtained an area result equal to zero, as shown in Figure 7. This Group B student has also changed his initial epistemological framing and now accepts that there is no triangle. He said that the difficulty of the task was high, so we interpreted it to mean that he found it difficult to accept that the triangle had no height and its area was therefore zero.



B37

Figure 7. Solution strategy by trigonometric functions performed per student B37.

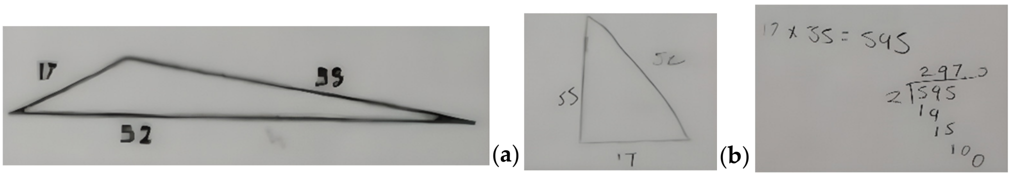
For the area formula method, Figure 8 shows the performance of student A27, who incorrectly draws a right triangle and incorrectly obtains an area of 297.5 cm^2. However, she says that she found the problem difficult because "I was unsure [. . .] as I had doubts about how to arrange the data of the triangle, and it is the case that using different base and height data gives a different area". In this way, we could observe that the student set up an incorrect initial epistemological framing by assuming that there was a right-angled triangle. During her solution process, she was unsure how to classify the length of the sides. In the end, she was not sure if her answer was correct. She also did not realize that the lengths of the sides contradicted Pythagoras' theorem.



A5

Figure 8. Performance of student A5 with the area formula strategy.

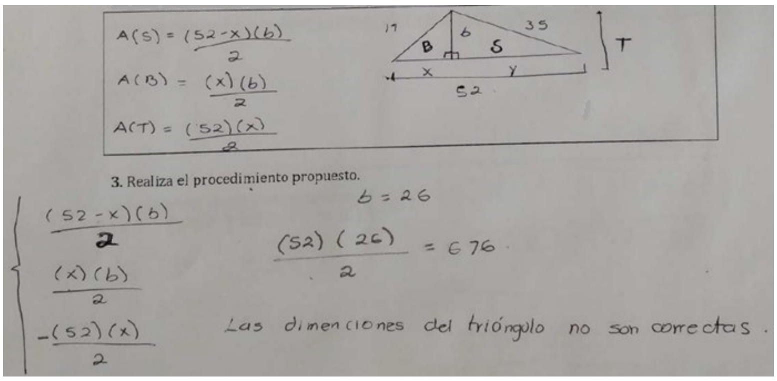
In the case of student B18, she also places the data in a right-angled triangle (Figure 9b) and calculates the area in exactly the same way as student A5 (Figure 9c). She also classifies the task as difficult and argues that she had doubts about the correctness of her answer because she could no longer remember some things. We interpreted that the student rotated the triangle given in the task (Figure 9a) on the assumption that it was a right-angled triangle in order to use a formula that she remembered. This student had difficulty selecting an appropriate epistemological resource to solve the problem. She only remembers the formula base times height over two, applies it, but is always unsure how to proceed. This is the reason she thinks the problem is difficult. She changes her initial epistemological framing by replacing the figure with one that she recognizes.



(**a**) (**b**) (**c**) B18

Figure 9. Response from student B18.

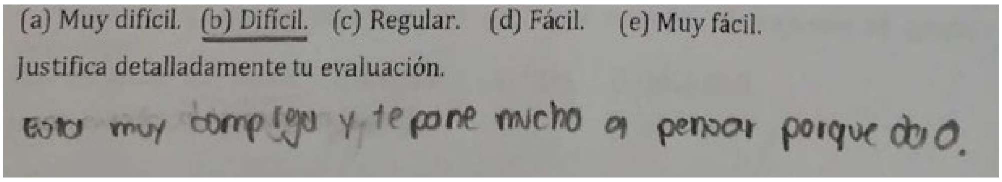
In the case of student B11, she suggests the following solution strategy: "To split the triangle into two parts, we get two new [triangles] with the bases x and y and the height b. From this data, we form a system of equations". Her procedure is shown in Figure 10. She correctly calculates the area of the right-angled triangles B and S, but not that of the entire triangle. Then she writes b $=$ 26 without justification and calculates the area to be 676 cm^2. At the end, however, she says "The dimensions of the triangle are not correct." This means that she has somehow realized that something is wrong, but she cannot see the reason. She classifies the task as regular.



B11

Figure 10. Performance of student B11 in the strategy area formula.

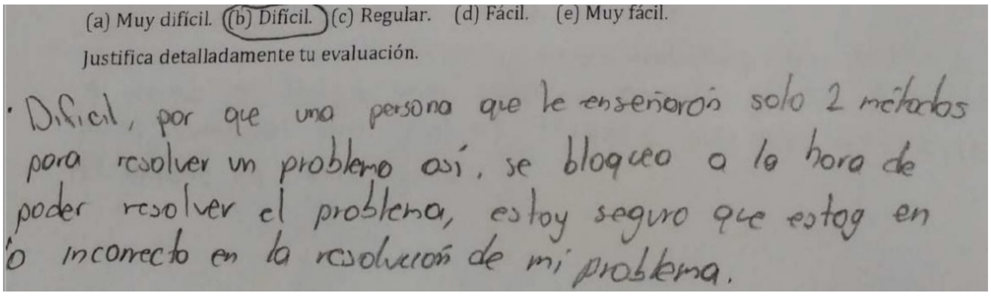
Regarding the students' perception of the difficulty of the task, Figure 11 shows the answer of student A14, who solved the task correctly using the Heron formula. He rated the task as difficult because, in his own words, "it is very complex and makes you think a lot because it gives 0". This comment is evidence that this student had a conflict with his original epistemological framing, which he needed to change. As he went through his solution process, he realized that the area was zero and wondered if that made sense. Since this student belonged to group A, in which the problem did not contain the illustration, he was able to modify his epistemological framing more easily during the solution process.


(a) Muy difícil. (b) Difícil. (c) Regular. (d) Fácil. (e) Muy fácil.
Justifica detalladamente tu evaluación.
Esto muy complejo y te pone mucho a pensar porque dio 0.

A14

Figure 11. Student comment A14 about the degree of difficulty of the problem.

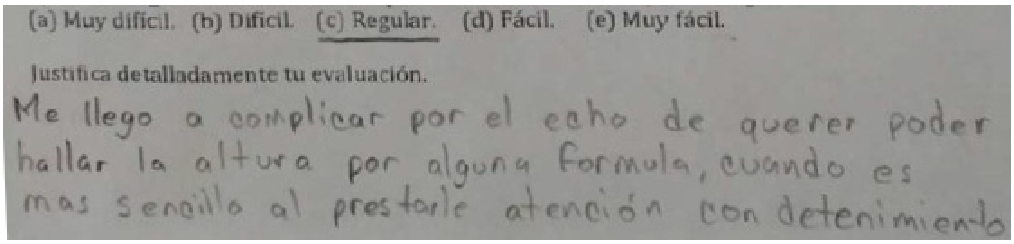
Another comment from a student in group A can be seen in Figure 12. Student A2 solved the problem correctly using the Heron formula, but he states: "[. . .] I am sure that I am wrong in solving my problem" and rates it as *difficult*. This result is evidence that his original epistemological framing remains, because although he has carried out the correct procedure, he does not believe in the result he has obtained.


(a) Muy difícil. (b) Difícil. (c) Regular. (d) Fácil. (e) Muy fácil.
Justifica detalladamente tu evaluación.
· Dificil, por que una persona que le enseñaron solo 2 metodos para resolver un problema así, se bloqueo a la hora de poder resolver el problema, estoy seguro que estoy en lo incorrecto en la resolución de mi problema.

A2

Figure 12. Student comment A2 about the degree of difficulty of the problem.

On the other hand, Figure 13 shows the comment of student B16 from Group B, who tried to solve the problem by unsuccessfully calculating the height of the triangle and then solved it when he realized that the sum of the two small sides was equal to the larger side. This student established the problem difficulty as *regular*. He said, "It was complicated for me by the fact that I wanted to find out the height by a formula, although it is easier to observe it exactly". This student was able to successfully change his initial epistemological framing by trying to find the height of the triangle and only later realizing that the triangle did not exist.


(a) Muy difícil. (b) Difícil. (c) Regular. (d) Fácil. (e) Muy fácil.
Justifica detalladamente tu evaluación.
Me llego a complicar por el echo de querer poder hallar la altura por alguna formula, cuando es mas sencillo al prestarle atención con detenimiento

B16

Figure 13. Student comment B16 about the degree of difficulty of the problem.

5. Discussion and Conclusions

The aim of this study was to analyze the epistemological framing that occurs in students during the solution process, depending on whether the problem has a triangle drawing or not. Based on the epistemological framing, we conclude that there are significant differences in students' solution processes as well as in students' perceptions of the difficulty of the problem. In the following, we will explain these two results in more detail.

The quantitative analysis showed that the percentage of students who solved the problem correctly without the triangle (67.6%) was significantly higher than the group of students who solved the problem correctly with the triangle drawing (43.9%). This means that the presence of the drawing with the triangle caused a difference in the initial epistemological framing that the students developed when reading the task, and that this framing influenced their solution process and final answer to the task. Students who solved the task with the triangle were more likely to give incorrect answers than those who did not have this element in the task. This result is consistent with the study by Juárez López et al. [16], in which 69 primary school teachers in training were given the task of calculating the perimeter of an irregular pentagonal surface from a fifth-grade math textbook. The task contained the figure of the pentagon with certain values on each side, but it was an impossible pentagon. The teachers were then asked: Can the terrain described in the task exist in reality? They were also asked to support their answer with arguments. Of the total number of teachers surveyed, 62 answered that *it can exist*. Only three teachers answered that *it cannot exist*, but of these, only one provided the correct argument.

Regarding the qualitative content analysis of the answers given by the students, the results show that students who solved the problem without the triangle drawing were able to perform a better solution process than students who solved the problem with the triangle drawing. In Group A of students, it can be observed that the initial epistemological framing, when the students read the problem without the triangle drawing, allowed them to preferentially rely on two solution strategies (Heron's formula and triangle inequality, with 75.6% between the two). It also allowed them not to make intentional arithmetic errors during their solution process and to obtain an area value equal to zero, which did not put them in conflict with their original epistemological framing. For the Heron formula, 81.8% of students solved the problem correctly by accepting that the area was zero, while 18.2% of students did not accept this result because they ignored the zero during their solution process. This means that in group A, the epistemological framework was naturally modified to accept that the area of the triangle was zero for most students.

Conversely, those students who solved the problem with the illustration made more errors in their solution processes. The most notable error was found in the Heron formula, where 71.4% of students made the same intentional math error by eliminating the partial result equal to zero and forcing a positive answer. Felicity's condition occurred when students interpreted that the drawing of a triangle in the task exists because such a triangle necessarily exists. Their initial epistemological framing, as expected by Gardner, led the students away from the correct solution approach. For the Heron formula, however, only 28.6% of the students in this group carried out the correct solution process. These students were able to change their original epistemological framing and regard the triangle as degenerate.

Furthermore, the drawing of the triangle in the task might encourage a solution procedure that leads some students to transform the original drawing, for which they do not have a ready-to-use formula to calculate the area, into a drawing to which they can apply a known formula (e.g., a right-angled triangle) (see, for example, the case of student B18 and Figure 9).

Generally speaking, during the solution process, students enter a cognitive conflict that leads them to two possible answer options:

i. They reconsider their original epistemological framing, change it considering the new situation, and give the correct answer;
ii. They deny the stated result, do not change their epistemological framing, and force a non-zero result.

In the last case, the students in Group B do not worry about whether the drawing is possible, i.e., whether the length of the sides matches the dimensions of the triangle, because they assume that the given graphical representation is correct.

In the case of Group A, where the problem statement does not contain the triangle drawing, the illustration was only useful to the students when they had to construct it themselves or not construct it, as happened in several cases when they realized that the data did not allow them to form it. In this case, students had the opportunity to explore the data provided by the task more freely. They changed their epistemological framing fluidly and adapted it to the new form during the solution process so that they could obtain the correct answer.

When analyzing the results of some students in Group B, it is noticeable that their epistemological framing changed as they solved the problem to find the correct answer. Some of them readily accepted the solution by trusting their mathematical procedure, while others did not trust their correct answer and stated that they were sure they had done something wrong. From this, we can conclude that all possibilities are present in the students. Some can change their epistemological framing more easily, and others cannot.

Regarding the students' perception of the difficulty of the problem, the students who solved the problem without the triangle drawing tended to mark the problem as difficult and regular with 86.4%, while the students who solved the problem with the drawing marked the same options with 65.9%. From this, we conclude that the students who solved the problem without the triangle generally found it more difficult than the students who solved the problem with the drawing, even though the latter ultimately gave more incorrect answers.

To summarize, this study shows the importance of giving students problems that do not contain erroneous drawings or warning them about them so that students can more easily change their epistemological framing during the solution process. It is important to see these types of problems as an opportunity for students to learn, reflect, and develop more flexible and adaptable epistemological framing during the mathematical problem-solving process.

A possible follow-up to this work could be the development of more flexible epistemological framings that are adaptable to the implausible conditions that may arise when solving mathematical problems, as an opportunity to recognize that Felicity's condition may not be so.

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education sciences

Article

Enhancing Competency-Based Education in Instrumental Analysis: A Novel Approach Using High-Performance Liquid Chromatography for Real-World Problem Solving

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Abstract: Curricula related to instrumental analysis aim for competency-based education to promote the development of teaching strategies that encourage students to successfully tackle the problem-solving and tasks inherent to their profession. However, this endeavor is constrained by the complexity of equipment and the lack of time in laboratory classes. The objective of this work is to present an alternative high-performance liquid chromatography (HPLC) practice that adapts the desired competencies to a shorter and more effective timeframe. It seeks more active participation from the student and contextualizes chromatographic analysis within a real-world problem that encompasses the entire analytical process, from sample to final result. In this scenario, the student receives a solid sample of spicy paprika from a supermarket and must report the level of spiciness in terms of the total amount of capsaicinoids. To achieve this, they must first apply different experimental conditions for extracting the analytes of interest (varying temperatures and solvents) and selecting the most optimal condition. This practice is designed for short sessions, specifically conducted in two 2.5 h laboratory sessions, and has been implemented in the subject "Advanced Techniques in Instrumental Analysis (ATIA)" in the fourth year of the Degree in Biotechnology at the University of Cadiz. The results obtained demonstrated a significant increase in student motivation and an improvement in the acquisition of skills; 100% of the students achieved a grade higher than seven in the final evaluation of their learning process.

Keywords: HPLC; analytical chemistry; capsaicinoids; instrumental techniques; extraction; laboratory practice; agrifood analysis

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1. Introduction

Currently, the globalization process has brought about many advancements of all kinds, primarily technological. Therefore, human beings are now required to have the ability to confront these changes by developing a series of skills, abilities, and critical thinking in order to achieve a proper education [1].

Nowadays, there is a strong consensus suggesting that, to promote improvement in thinking skills, it is necessary to create a conducive learning environment for students to take an active role in the process. According to Travieso et al. [2], there are three principles related to learning. The first one is to value learning by the students as a system of construction rather than passivity. The second principle is based on the impact of metacognition on knowledge utilization, with metacognition understood as an awareness of one's own thought processes and understanding the patterns behind them. Lastly, the third principle emphasizes the social nature of learning. This implies that students can explore complex problem situations by posing open-ended questions that guide discussion, exchange of ideas, and meaning construction.

These active methodologies aim to foster knowledge construction through inquiry, reflection, creativity, and problem solving [3]. Their effectiveness is contingent upon role changes throughout the learning process, with the teacher taking on the role of facilitator or guide, while still recognizing that the teacher also has to teach, as not everything can be learned autonomously. The methodological proposal of Problem-Based Learning (PBL) is an appealing alternative to implement this active methodology. It is the means by which the activities aimed at promoting active and direct participation of students throughout the teaching–learning process are made possible. PBL stimulates interpersonal relationships and communication skills, develops research skills, and promotes reflection and analysis [4,5].

One of the current premises in curricula, concerning content related to Instrumental Analysis, is to promote the development of teaching strategies that encourage students to acquire basic skills in the field of chemistry, such as sample preparation, handling of materials, instrumentation, and data analysis. These competencies aim to foster their creativity and autonomy [6], and therefore, new methodologies are considered that enable competency-based education, allowing for comprehensive development of the individual [7]. One of the main objectives of laboratory sessions is for students not only to acquire isolated knowledge of different techniques but also to have the ability to correctly apply the acquired knowledge in solving real analytical problems within their field of study and with autonomy [8]. The role of the laboratory in the teaching–learning process, in addition to consolidating conceptual concepts, provides students with the procedural content and basic skills they will need in their future professional endeavors. However, the complexity of the equipment, the limited time dedicated to laboratory practice in the curricula, and the cost of materials make it difficult to acquire these skills. These limitations result in conventional laboratory practices, where procedures similar to a "cookbook" are followed, ensuring that they are completed within the stipulated time without deviations in results and increased costs [9]. Students are provided with a protocol they must strictly adhere to, leaving no room for improvisation, thus creating a learning situation that does not foster student autonomy and limits the meaningful learning of content. For this reason, it is necessary to establish training strategies in these subjects where students take on a more active role in their learning, make decisions, and construct their own knowledge [10]. These proposals must be everyday real problems of their profession but ensure, at the same time, that they can be solved in the laboratory session and at no greater cost than conventional ones [11]. However, despite the theoretical simplicity of these problems, they should serve as the fundamental basis for achieving the learning objectives established as requirements for passing the course. Additionally, through the use of this methodology, students will develop other competencies, such as collaborative work, learning to work in teams, dividing tasks, learning communication strategies, and promoting peer teaching (explaining to others) [12,13]. Thus, this work is generally established as Problem-Based Learning (PBL) adapted to the context of instrumental analysis within analytical chemistry. This learning methodology has been widely used at various educational levels [14–16] with the aim of enabling students to develop self-directed learning habits, problem-solving skills, and deep disciplinary knowledge [17–19].

Based on all of the above, a practical exercise has been designed to develop students' autonomy and cooperation skills while being motivating and adapting to the infrastructure and limitations of an educational institution. In this way, it can be conducted in a few hours, successfully contextualizing to the students' environment, the chromatographic analysis within the analytical process, starting from a real problem [20]. In this practice, the student takes on the role of a quality manager in a laboratory, who must provide a client with the total amount of spiciness of a batch of supermarket paprika samples to add this information to its labeling. To do this, they need to determine the total concentration (mg/g) of capsaicinoids in the paprika. Many authors advocate for the utility of case studies, as using real-life examples from their profession in the teaching–learning process increases interest and the degree of knowledge assimilation and fosters students' attitudes and aptitudes [21].

Thus, the objectives pursued by this practice are:

- Understanding the concept of extraction and the optimization of the most influential parameters to obtain the greatest number of compounds of interest from a sample. Knowing extraction methods for natural compounds in samples of biotechnological interest and being able to choose the most appropriate method according to the nature of the sample;
- Familiarizing the student with high-performance liquid chromatography (HPLC), including its application, handling the instrumentation, preparing calibration curves, learning to separate and detect compounds, and the pre-treatment of sample extraction;
- Working in teams, developing communication skills, and interaction among students;
- Learning to interpret, compare, and explain the results obtained;
- Understanding the importance of the different stages of the analytical process to solve an initial analytical problem by reporting the analytical results.

In this way, the laboratory session proposed as a model employs a real-life situation where students identify fundamental problems they are unfamiliar with, obtain new learning objectives that allow them to deepen their understanding of the content, retain information, and develop additional competencies beyond those of the subject itself [22].

Thus, the objective of this practice is for students not to view instrumental techniques in isolation and analyze samples following a standard protocol but rather to face decision-making and to assess the importance of sample pretreatment, the amount of sample to be taken, the selection of experimental conditions in extraction, and critical interpretation of the results, while simultaneously developing their skill in laboratory operations.

2. Methodology

2.1. Sample

The starting sample is a commercial container of spicy paprika obtained from a local store. Spicy paprika was chosen because it is easy to obtain and handle and is non-contaminating and non-hazardous. Additionally, it is economical, and the fact that it is a sample known to the students further arouses their curiosity, as they see it as a more familiar product. The student decides how much of the sample, between 1 and 2 g, to take from the container for the practical exercise.

2.2. Materials and Reagents

To carry out this experiment, a specialized laboratory for analytical chemistry is required, equipped with balances, spatulas, thermometers, wash bottles, stirring plates, an ice bath, scissors, filter paper, a high-performance liquid chromatography instrument, and an adequate supply of glassware. Specifically, in addition to the common equipment and materials, for each pair of students, the following material is necessary:

- Two 50 mL volumetric flasks;
- Three 100 mL beakers;
- A 600 mL beaker;
- A 50 mL graduated cylinder;
- A 5 mL syringe with a needle;
- Two nylon syringe filters;
- Two Pasteur pipettes and 2 rubber bulbs;
- A conical funnel;
- A Teflon-coated magnet;
- Two HPLC vials with their respective caps.

For the preparation of the extracts, Milli-Q water is used, in this case obtained through a Millipore water purification system (Bedford, MA, USA). And, HPLC-grade methanol was acquired from Panreac Quimica S.A.U. (Castellar del Vallés, Spain). For chromatographic separations, acetic acid is employed, in this case obtained from Merck (Darmstadt, Germany).

2.3. HPLC Instrumentation

The sample analysis is conducted at room temperature using a high-performance liquid chromatography (HPLC) system from JASCO (Tokyo, Japan), composed of an autosampler (Intelligent Sampler AS-2055 Plus), a pump (Intelligent HPLC Pump PU-1580), a mixing unit (Quaternary Gradient Unit LG-1580-04), a solvent degasser (Degasys Populaire), a UV-Vis detector (Intelligent-UV-Vis Detector UV-1575), a LiChrospher® 100 RP-18 column (Merck KGaA 64271, Darmstadt, Germany) (250 mm × 4 mm, 5 µm particle size), and a control interface (LC-NetII/ADC).

The method for separating capsaicinoids has been previously developed by the subject instructors. It employs two elution solvents: water (solvent A) and methanol (solvent B), both acidified with 0.1% acetic acid. The separation gradient used is shown in Table 1:

Table 1. Separation gradient employed for the chromatographic separation.

Time (min)	0	2	7	9	18	20	25	30	32	38	40	50
%B	0	55	55	60	65	65	70	70	100	100	0	0

The solvent flow rate was 1 mL/min. The detection of capsaicinoids was carried out through UV-Vis spectrophotometry, measuring these compounds at their maximum absorption wavelength (280 nm).

The HPLC chromatograms were processed using DropView software (Version 1.1), and manual integration was performed following well-accepted criteria applied to chromatographic methods [23].

2.4. Practice Organization and Timetable

Table 2 displays the tasks carried out during the two practical sessions, along with the allocated time for each to achieve the set objectives. It also outlines the skills that students should overcome and acquire.

Table 2. Temporal organization of the contents developed in the practice along with assimilated competencies.

CONTENTS	TIMING (MIN) 30	60	90	120	150	COMPETENCES
SESSION 1						
Brief introduction						Contextualization of the practice within a real analytical problem.
Sample weighing						The student takes on a more active role in their learning and begins to make decisions.
Extraction procedure and analysis by HPLC system						Safely handling chemical materials and developing laboratory skills that will be essential for their future profession. Cooperating with other students through teamwork.
Identification of HPLC instrument parts						Consolidation of conceptual contents.
SESSION 2						
Chromatogram integration						Utilize tools and computer programs to process experimental results.
Identification and quantification of capsaicinoids						
Data interpretation and conclusions. Analytical problem solving						Interpret data from laboratory measurements. Apply critical reasoning, as well as theoretical and practical knowledge, and learn to make decisions in the face of real problems.
Report compilation						Compile and write scientific and technical reports.

As can be seen in Table 2, the laboratory practice is divided into two sessions of 2.5 h each. In addition, each session is divided into 15 min intervals to understand the temporal organization of the tasks carried out within them.

- Session 1 (150 min): Sample collection, preparation, and treatment. The isolation and separation of the compounds of interest from the sample matrix are prerequisites for any analysis process and involve several stages, such as extraction, preconcentration, and purification [24]. This laboratory session begins with an introduction to the importance of sample collection and the extraction of the target analytes from paprika prior to HPLC analysis. Paprika is a solid substance, so solid–liquid extraction is necessary to make the target analytes (in this case, capsaicinoids) accessible for analysis. Currently, there are many sophisticated solid–liquid extraction techniques. However, by using magnetic stirring, a simple technique with equipment available in any university laboratory, very realistic results can be obtained in a short period of time [25]. Students follow a general protocol for the experimental procedure, including the parameters to be studied. They will assess different extraction conditions to ultimately determine the optimal one. With the guidance of the professor, students have the freedom to make some decisions, such as the quantity of the starting sample or the volume of the extract to prepare. Once the extracts are prepared, students move on to the HPLC equipment, where the instructor introduces them to the most important parts of the equipment (type of solvents, column, pump, autosampler, degasser, and detector) and the connection between them, and emphasizes the importance of the analysis procedure conditions. A sequence is set up with all the students' samples under various conditions for analysis;
- Session 2 (150 min): Analysis and interpretation of results. Students visualize the results of their samples, for which they must integrate the obtained chromatograms. Once the target analytes are integrated, students record the area data for each one. Next, using the data provided by the instructor, they calculate the calibration curve using an external standard and proceed to calculate the amount of spiciness obtained in their samples. Students also have the data obtained by all the students, allowing them to compare the optimal extraction conditions. Once these conditions are selected, they

proceed to calculate the amount of spiciness provided by each compound, identifying the predominant one and the total amount of capsaicinoids of the starting sample (mg/g).

2.5. Experimental Procedure

The practice script is given to the students, and they are paired up to carry out the experiments. First, different conditions are optimized to determine which one is the most suitable for extracting a greater amount of the compounds of interest (capsaicinoids). To achieve this, two extraction solvents (water and methanol) and different temperatures (0 °C, room temperature 20 °C, and 50 °C) are evaluated. All temperatures are controlled. To maintain the temperature at 0 °C, an ice bath is used, while a heating plate is used to reach 50 °C.

2.5.1. Step 1: Extraction of Capsaicinoids Using Magnetic Stirring

The sample preparation procedure is shown in Figure 1 and consists of the following steps: 1–2 g paprika are weighed in a beaker using a precision balance (Figure 1A). Each student records the weight, as the capsaicinoid concentration obtained will depend on the amount of starting sample. Next, approximately 30 mL of solvent (water or methanol, depending on the experiment) are added using a graduated cylinder. To initialize the magnetic stirring extraction, a magnet is introduced, and the mixture is placed on a heating plate for 10 min. It is very important to take into account the extraction conditions that will be carried out to place an ice-water bath or a heating plate to control the appropriate temperature (Figure 1B). Subsequently, to remove solid residues, gravity filtration is performed in a 50 mL volumetric flask using a funnel and a conical or folded filter (student's choice) (Figure 1C). It is convenient to emphasize the importance of thoroughly rinsing the beaker to prevent any sample loss that could lead to errors in the measurement. Once filtered, the flask is filled to the mark with the same solvent used for the extraction. To prevent any impurities that may clog the chromatographic column, it is necessary to filter the extract using a 0.45 μm diameter nylon filter (Figure 1D). For this, 2–3 mL of the extract are taken with a syringe and filtered into a 2 mL chromatographic vial, which is labeled and placed in the HPLC equipment's autosampler for subsequent analysis.

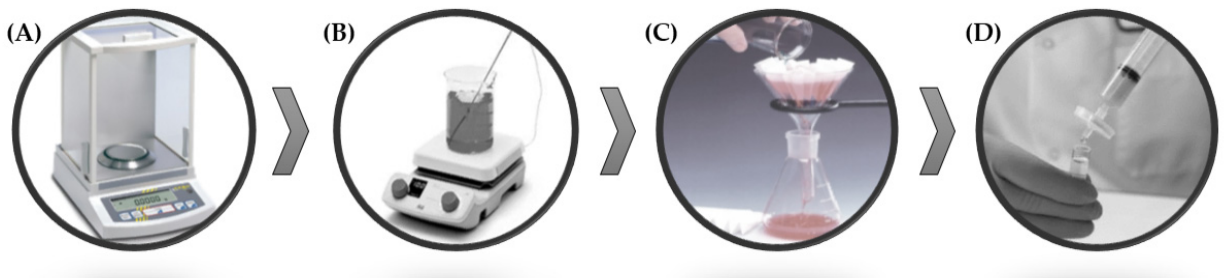

Figure 1. Diagram of the experimental procedure followed by the students in the laboratory. (**A**) Weighing of the sample; (**B**) extraction of the compounds of interest; (**C**) gravity filtration of the extract; and (**D**) filtration using a syringe filter.

2.5.2. Step 2: Separation and Quantification of Capsaicinoids

First, the separated compounds are identified based on their retention time, using prior knowledge from the instructors. The spicy flavor of peppers is due to a group of molecules exclusive to these fruits, the capsaicinoids. They are acidic amides formed from branched-chain fatty acids C9–C11 and vanillylamine [26]. Although more than 20 capsaicinoids have been found in peppers, the most predominant are capsaicin (C) and dihydricapsaicin (DHC), representing around 90% of the total content. The rest is mainly represented by nor-dihydrocapsaicin (n-DHC), homo-capsaicin (h-C), and homo-dihydrocapsaicin (h-DHC). In Figure 2, the chemical structures of the five most abundant capsaicinoids found in nature can be observed, which differ in the length of the carbon chain and the presence of unsaturations [27].

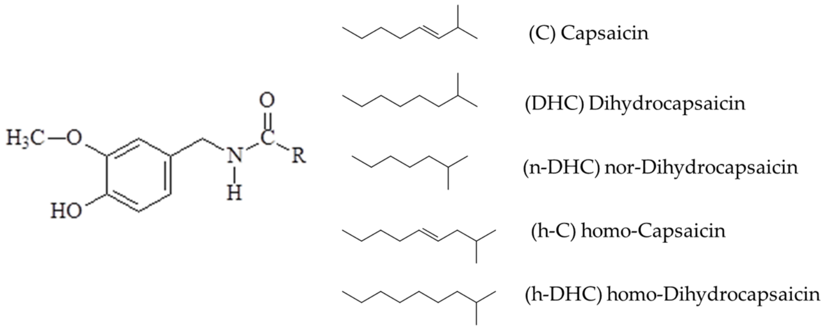

Figure 2. Structures of the main capsaicinoids identified in peppers.

The five major capsaicinoids identified in the analyzed paprika sample elute in the following order: n-DHC, C, DHC, h-C, and h-DHC. These are relative non-polar compounds because, despite having a phenol group in their structure, they have an aromatic ring and a hydrocarbon chain. It is observed that, as the length of the aliphatic chain increases, as in the case of h-C or h-DHC, the retention time also increases. This is because the stationary phase (C18) is a reverse phase, so the higher the number of carbon atoms in the side chain, the lower the polarity of the structure. Consequently, it is more retained by the C18 column and takes more time for elution. Subsequently, the quantity of these capsaicinoids is determined from the chromatogram obtained at 280 nm, which is the wavelength of maximum absorption for this compound family (Figure 3).

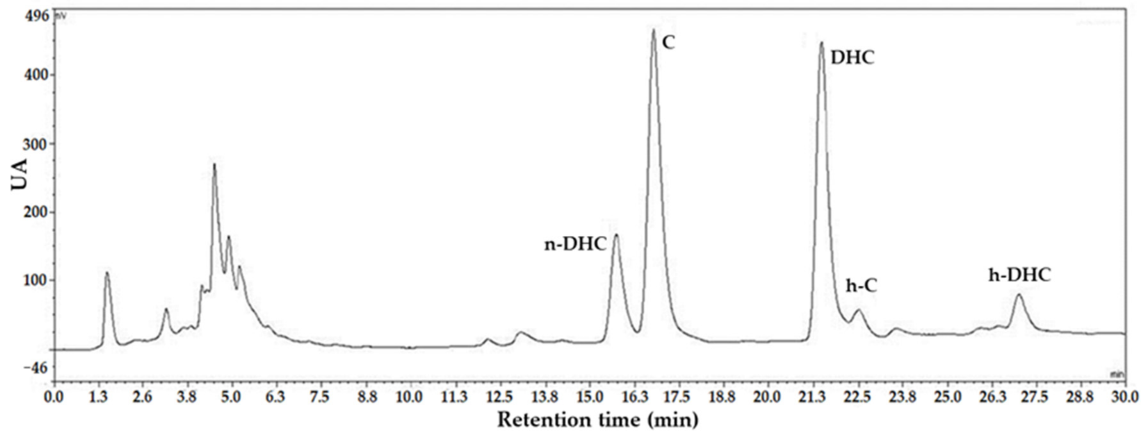

Figure 3. Chromatogram of the most abundant capsaicinoids present in the pepper (n-DHC (nor-dihydrocapsaicin), C (capsaicin), DHC (dihydrocapsaicin), h-C (homo-capsaicin), and h-DHC (homo-dihydrocapsaicin)) obtained with the equipment used to conduct this laboratory practice.

For the quantification of the analytes, it is necessary to first develop a calibration curve. Due to the difficulty and cost of obtaining standard substances for the capsaicinoids under study, the instructors have previously prepared the calibration curve using an external standard of nonivamide, a type of capsaicinoids not as abundant in peppers as the ones studied but with similar characteristics. The data obtained for the calibration curve are provided to the students and are shown in Table 3.

Table 3. Data provided by the teaching group for the calculation of the calibration curve of the nonivamide standard.

Concentration of Nonivamide (mg/L)	Area (Signal)
4	68,373
10	237,451
40	1,011,445
100	2,702,310

After that, the students are required to calculate the calibration curve in the range of 1–100 mg/L of spiciness through least squares linear regression. As this is an external standard calibration, students can interpolate the value of the areas obtained in each case to calculate the concentration of each of the capsaicinoids under different extraction conditions in the starting sample, as well as the total capsaicinoids concentration (mg/g), which is the goal of this practical exercise [28].

2.5.3. Step 3: Conclusions, Final Explanation, and Sharing of Results

The limited time in laboratory sessions prevents students from carrying out all experiments in duplicate, and each student may not be able to perform all extraction conditions. However, considering the importance of replicates in analysis, instructors put in common the data obtained by all students. In this way, students have the information to calculate the average value of the total capsaicinoid concentration alongside its standard deviation under each condition, allowing them to assess the most optimal extraction condition. With access to all the data, students must critically interpret the results, making decisions, such as discarding any outlier, justified statistically.

Students must report the final value of the total capsaicinoid concentration (mg/g), which is the overall objective of the practical exercise. To achieve this, they prepare a lab report explaining the methodology they have followed, as well as a discussion of the results. Additionally, in order to assess the assimilation of concepts related to the development of the chromatographic method and the fundamental principles of chromatography, students must answer some questions related to the laboratory session, which will be presented below with the correct answer for each of them.

2.6. Teaching Strategies

Some considerations that need to be emphasized to the students during the development of the practical exercise are as follows:

- Weigh between 1–2 g of the sample. Emphasize that it is not necessary to weigh a fixed amount; what is important is to accurately record the weight taken for later inclusion in the calculations. The capsaicinoid concentration will depend on the initially weighed quantity;
- Measure the extraction volume with a graduated cylinder: This volume can be approximate; what is crucial is that, subsequently, the obtained extract is brought to an exactly known volume for reference. This is why it is made up to the mark in a 50 mL volumetric flask.

Moreover, some recommendations to be taken into account:

- Given the time allocated for the practice, students should start by using water as the first solvent, as this process involves a longer filtration time, and finish with a hot methanol extraction, as the cooling of the heating plate is a rather slow process;
- Monitor temperature very carefully to prevent boiling and solvent losses due to splashing or evaporation, which could lead to errors in the analysis.

2.7. Security Considerations

This practice does not involve exceptional safety measures. Students should use the appropriate personal protection equipment: splash-resistant protective glasses, latex or nitrile gloves, and a laboratory coat.

Spicy paprika is a common food; however, it is true that capsaicin, the major component of hot peppers, is highly irritating if it comes into contact with the skin and eyes. So, if that happens, it should be washed with plenty of water.

Methanol will be used in the fume hood due to the hazards defined in its labeling. It is a liquid that can generate harmful and highly flammable organic vapors (H225). Additionally, it is toxic if ingested, comes into contact with the skin, or is inhaled (H301 + H311 + H331). Finally, it can cause damage to the central nervous system and visual organs (H370).

The waste generated in this practical exercise is limited to a small amount of leftover extracts with methanol, which will be disposed of in the non-halogenated organic solvent safety container. Filters with remnants of paprika can be discarded in the regular trash bin.

3. Results and Discussion

HPLC is commonly used as a successful tool for the separation, determination, and quantification of biological compounds in a wide variety of complex matrices [29]. Additionally, it has become the dominant analytical technique for achieving rapid separations in all industries, such as pharmaceutical [30], agrifood [31], environmental [32], and forensic chemistry [33]. For this reason, chromatography is an important chapter within any degree related to instrumental analysis or analytical chemistry, requiring students to acquire skills for their future careers. In this section, the results of the laboratory practice, as described and carried out in the Advanced Techniques in Instrumental Analysis course in the fourth year of the Biotechnology Degree at the University of Cadiz, are presented. Specifically, the results obtained by students during the years 2014 to 2022 are included, involving a total of approximately 400 students. The two practical sessions, each lasting 2.5 h, have been implemented to complement the knowledge acquired during the theoretical part of the course. Each session has had a total of students ranging between 20–30 that have been divided into pairs. Students had to prepare the sample, create a calibration curve, analyze the samples, and interpret the final results. Below are the average results obtained at different stages.

3.1. Obtaining the Optimal Extraction Condition

As mentioned earlier, the main goal is that students take a more active role. Therefore, a real-world problem is presented: reporting the data on the total spicy content to label the product. In this experiment, students explored the following extraction conditions: water at room temperature, methanol at 0 °C, methanol at room temperature 20 °C, and methanol at 50 °C. Due to the limited time in the session, not all students performed all extractions. Instead, they were divided into two groups, with each group conducting two extraction conditions. Thus, each condition was carried out by a total of 10, 12, or 14 students, depending on the number of students enrolled each year when the experiment took place. All extracts were analyzed by HPLC. Subsequently, the results obtained by the different groups were discussed to conclude which extraction conditions are the most suitable for this type of analyte.

In the resulting chromatograms, several peaks were observed; however, only five of them corresponded to capsaicinoids: n-DHC, C, DHC, h-C, and h-DHC. The remaining compounds are sugar and other analytes that also absorb at 280 nm. As mentioned earlier, the compounds were previously identified by the professors based on their retention times, and students had access to this information. On the other hand, with the information provided in Table 3 on the external standard, the students calculated the calibration curve ($y = 27403x - 50133$, regression coefficient $R^2 = 0.9996$, LOD = 0.58 mg L^{-1}, and LOQ = 1.30 mg L^{-1}). The negative value of the intersection of the axis on the calibration curve means that a minimum analyte concentration is needed to be detected by the equipment. So, once the compounds of interest were identified, they proceeded to integrate the peaks and apply the calibration curve they calculated the concentration of all capsaicinoids under the different conditions. Based on the provided information, they selected only those compounds from the chromatogram under study in this practical exercise. In this way, they understood the importance of knowing retention times for compound identification because, as mentioned, other analytes can also absorb energy at the same wavelength as capsaicinoids. Table 4 displays the average results obtained by one of the practice groups for each condition. Students were asked to fill in the table according to their group and condition, and then a collective discussion of all classmate's results was conducted. The presented results are based on peak integration (areas).

Table 4. Experimental data generated by students for different extraction conditions.

	Areas				
Condition	**n-DHC**	**C**	**DHC**	**h-C**	**h-DHC**
H_2O	-	101,944	59,686	-	-
	-	102,353	54,591	-	-
	-	93,256	10,035	-	-
	-	104,944	56,930	-	-
	-	102,472	58,216	-	-
MeOH 0 °C	60,158	2,210,314	1,121,434	23,811	37,553
	57,041	2,382,413	1,196,785	29,115	35,043
	59,258	2,474,408	1,224,932	31,082	36,079
	53,390	2,575,229	1,209,333	27,549	39,088
	55,530	1,995,281	1,011,710	25,368	34,425
MeOH 20 °C	131,487	1,718,834	1,000,336	34,761	20,421
	142,756	2,376,237	1,295,771	42,023	42,123
	133,728	2,313,358	1,347,653	42,653	39,510
	135,919	2,404,508	1,358,370	37,641	46,295
	141,021	2,343,898	1,395,074	32,799	43,978
MeOH 50 °C	170,896	2,802,853	1,388,149	33,705	48,709
	173,859	2,738,292	1,441,871	33,651	46,540
	184,450	2,782,409	1,358,398	39,318	55,887
	179,338	2,828,097	1,374,411	36,743	46,953
	172,397	2,917,026	1,403,212	34,668	52,133

From the obtained areas and by interpolation on the calibration curve, taking into account the initially weighed amount of paprika, the students determined the concentrations of each capsaicinoid as well as the total concentration in the solid sample (mg/g) under different extraction conditions (Table 5). It is crucial for each student to use their initial weight and recognize the importance of accurate weighing, as the total capsaicinoid concentration depends on the quantity of the starting sample. At this stage, students also grasp the significance of proper calibration curve usage and the importance of the final data, which must be of high quality and interpretable for the client. They cannot, for instance, directly report the data obtained from the calibration curve, as the quantity of the starting sample and any stage in the entire analytical process can influence the result. If done correctly, any stage prior to analysis should not interfere with or alter the final data.

Table 5. Capsaicinoid concentration (mg/g) in the solid paprika sample for each of the extraction conditions.

		Concentration of Capsaicinoids in the Sample (mg/g)					
Condition	**Weight**	**n-DHC**	**C**	**DHC**	**h-C**	**h-DHC**	**Total**
H_2O	1.0244	-	0.27	0.19	-	-	0.47
	1.0150	-	0.27	0.18	-	-	0.46
	1.0000	**-**	**0.26**	**0.10**	**-**	**-**	**0.36**
	0.9930	-	0.28	0.20	-	-	0.48
	1.1850	-	0.25	0.18	-	-	0.44
MeOH 0 °C	1.0000	0.20	4.12	2.14	0.13	0.16	6.76
	1.0030	0.19	4.42	2.27	0.14	0.15	7.19
	1.0120	0.20	4.55	2.30	0.15	0.15	7.35
	1.0006	0.19	4.78	2.29	0.14	0.16	7.58
	0.9020	0.21	4.14	2.15	0.15	0.17	6.82
MeOH 20 °C	**1.0090**	**0.32**	**3.19**	**1.90**	**0.15**	**0.13**	**5.71**
	1.0020	0.35	4.42	2.45	0.17	0.17	7.55
	1.0120	0.33	4.26	2.52	0.16	0.16	7.44
	1.0070	0.34	4.45	2.55	0.15	0.17	7.67
	1.0530	0.33	4.15	2.50	0.14	0.16	7.29
MeOH 50 °C	1.0150	0.39	5.13	2.58	0.15	0.18	8.44
	0.9990	0.41	5.09	2.72	0.15	0.17	8.56
	1.0000	0.43	5.17	2.57	0.16	0.19	8.52
	0.9999	0.42	5.25	2.60	0.16	0.17	8.61
	1.0020	0.40	5.40	2.65	0.15	0.18	8.79

All students had access to their peers' data to determine the optimal extraction conditions for any compounds of interest. Prior to performing the calculations, they had to identify if there were any outliers by applying the Q-Dixon test. To this end, they compared the calculated Q with the tabulated Q, and in cases where Qcalculated > Qtabulated, they rejected the data. A p-value less than 0.05 was set as statistically significant. The outlier values excluded from the analysis are highlighted in bold in Table 5.

Based on the results obtained, students had to create a comparative graph of the average (and standard deviation) concentration of each individual capsaicinoid for each characteristic of the extraction method, using all the data from all groups (Figure 4). With this, the students observed and discussed, using critical reasoning, which was the optimal condition or the trend they followed. In doing so, they developed some of the aforementioned competencies, such as learning to interpret results through graphing, sharing results, or using their own knowledge and critical reasoning skills to draw conclusions from the obtained results.

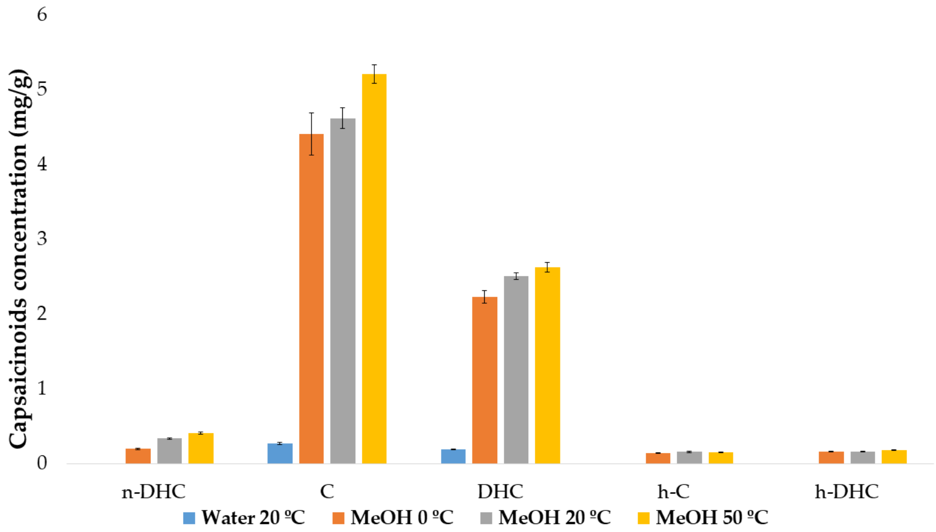

Figure 4. Average concentration of individual capsaicinoids for different extraction conditions.

After comparing and discussing the results, the students concluded that, regardless of the extraction conditions, capsaicin was the predominant capsaicinoid, followed by dihydrocapsaicin, with the latter being approximately half the concentration of C. Furthermore, as mentioned in the introduction, it was confirmed that both major capsaicinoids together represent around 90% of the total concentration of capsaicinoids in the analyzed sample. Finally, they observed that the other three capsaicinoids, n-DHC, h-C, and h-DHC, were present in very similar concentrations (with n-DHC slightly higher than the other two) and significantly lower than the major ones.

Finally, students were asked to create a graph with the average (and standard deviation) concentration obtained under each extraction condition (Figure 5). In this way, they confirmed that the total amount of capsaicinoids in the paprika sample analyzed by HPLC ranged from 0.45 to 8.60 mg/g of the sample depending on the conditions.

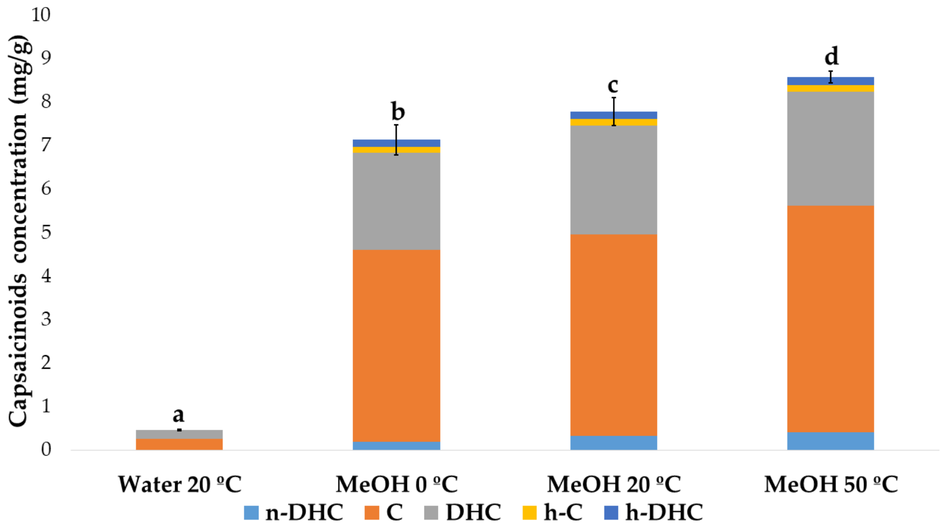

Figure 5. Average concentration of capsaicinoids (mg/g) for different extraction conditions. Different letters (a, b, c, and d) indicate the presence of significant differences between the conditions.

Through visual inspection, all of them noted that a smaller amount of capsaicinoids was extracted with water compared to methanol. However, to make an objective comparison of the results and determine if there were significant differences between the use of solvent and/or temperature, the students conducted an ANOVA, specifically the Student's t-test (p-value < 0.05), that supported the results statistically.

Based on the results obtained, the students concluded that methanol extracts are better at any temperature than water for any of the analyzed capsaicinoids, since the concentration obtained is much higher. This is due to the high polarity of water compared to that of the compounds of interest, which have an aromatic ring and a hydrocarbon chain in their structure [34]. On the other hand, they observed that, as the extraction temperature increases in the case of methanol, the concentration of extracted capsaicinoids also increases. This is because higher extraction temperatures accelerate movement, penetration, dissolution, and molecular diffusion to promote the release of bioactive compounds [35]. Moreover, a higher temperature also causes structural denaturing of proteins, e.g., cell-wall degradation, and thus greater access to the contents of the cells. Based on the ANOVA results, the students concluded that there were no significant differences between 0 °C and 20 °C, but there were significant differences at 50 °C. Therefore, the optimal condition reported by the students for the extraction of capsaicinoids was methanol at 50 °C, and thus, the final value reported to the client was 8.58 ± 0.13 mg/g.

3.2. Student Experience and Evaluation

The assessment of the learning situation was initially conducted with a series of questions during the theoretical explanation to understand the students' prior knowledge and to build upon their existing understanding. Throughout the activity, this learning process was also evaluated. At the end of the first day of practical sessions, the students were gathered to receive an explanation about the HPLC equipment used. In this way, they could physically see each part of the equipment they had been studying in the theory class and become familiar with it. Furthermore, group discussion was encouraged to support reflection on the results they expected to obtain based on the appearance of the samples under each of the conditions and the polarity of the solvents and temperatures used. At this point, the professor can identify if there are any misconceptions, for example, if they understand the relationship between polarity and temperature with the color of the vial and, therefore, with the amount of compounds extracted under each condition, the importance of optimizing different conditions, how the separation and quantification of compounds are carried out, or why it is necessary to know the exact initial weight of the sample, which will be addressed to ensure full comprehension.

When all the content had been covered, in the second session, a final assessment was requested in the form of a laboratory report, which helped reinforce the acquired knowledge and was used to evaluate the learning objectives. In this report, students were required to process all the data and engage in a critical discussion thereof. Additionally, they had to answer a series of questions to assess whether they had correctly understood the foundation of the practice and the concepts under study. The report grading heavily relies on the analysis and interpretation of results, enabling the drawing of conclusions from the analytical data obtained.

The questions they had to answer in the report, along with their correct responses were as follows.

Q1. What effect does the extraction solvent have on the extraction of capsaicinoids? Explain the values observed as a function of the polarity of the analytes studied and the extraction solvents used.

The main objective of using the solvent in extraction is to release the analytes of interest contained in the sample, thus obtaining the analytes in solution for subsequent LC analysis. Depending on the nature of the solvent, a higher or lower concentration of these analytes will be obtained. Capsaicinoids are considered analytes of intermediate polarity because they have both polar and nonpolar components. For a successful extraction, it is necessary for the solvent used to have a polarity similar to that of the analyte to be extracted. The solvents used in this practice are methanol and water. Based on the results obtained, it is observed that methanol extracts a greater amount of capsaicinoids compared to water because it has a polarity more similar to that of the analyte under study. Both are polar solvents; however, water, being more polar, will have less affinity for less polar capsaicinoids, resulting in a poorer extraction.

Q2. What effect does the extraction temperature have on the extraction of capsaicinoids? Justify the answer.

In the experiment, extractions were carried out at different temperatures: 0, 20, and 50 °C. Observing the results obtained, the efficiency of the extraction increases with temperature, meaning that higher temperatures result in higher concentrations of capsaicinoids. This is because, as the temperature increases, both the extraction rate and the solubility of the analyte in the solvent increase, facilitating its extraction. However, it should be noted that excessive temperature increase can lead to degradation of the analytes and/or evaporation of the solvent.

Q3. What type of column have you used? Why? Comment in this regard, the solvent used in the separation, as well as their elution order.

In this chromatographic analysis, a C18 column has been employed, as the work is performed in reverse phase, meaning that the column used in the extraction as the stationary phase is nonpolar, and the mobile phase eluents are polar (water and methanol, both acidified with 0.1% acetic acid).

For effective elution, the order in which solvents are added should be water first because it has a polarity more different from the stationary phase, and later methanol gradually, as its polarity is more similar to the stationary phase. The solvent, depending on its polarity, will carry those analytes with more affinity for it through the column faster, allowing the separation of different analytes based on their retention time on the column. Since water is more polar, analytes with a higher polarity (greater affinity for the solvent) will be carried out through the column first, and after adding methanol, analytes with a lower polarity begin to elute. More apolar compounds will remain retained on the column for a longer time due to hydrophobic interactions because of their greater affinity.

Q4. Indicate the type of elution used in the chromatographic separation and represent it graphically (%methanol vs. time). In view of the graph, make comments on it (ramps, periods in isocratic, column washing, column conditioning, etc.).

For the separation of the target capsaicinoids present in the sample, a gradient chromatographic separation method has been employed (Figure 6).

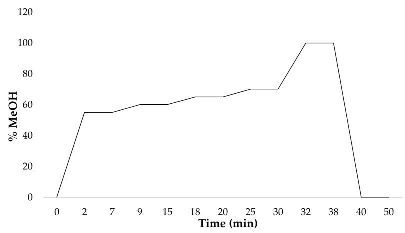

Figure 6. Graphical representation of the chromatographic gradient used for the separation of the target capsaicinoids present in the paprika sample.

Through the graph, it can be observed that the elution of the sample occurs during the first 32 min. Within this time frame, there are four isocratic periods, moments when the solvent concentration remains constant (slope 0): from minute 2 to 7 (55%), minute 9 to 15 (60%), minute 18 to 20 (65%), and minute 25 to 30 (70%). After this, the column-washing phase begins until minute 38, reaching 100% methanol to ensure the complete elution of any remaining analyte in the column. Subsequently, the methanol concentration is decreased to 0% to return to the initial conditions, resulting in column conditioning until minute 40. Finally, from minute 40 to 50, column equilibration takes place to prepare the equipment for the injection of the next sample.

Q5. Why was a small amount of acetic acid added to the solvents?

Adding a small amount of acetic acid prevents the deprotonation of the analytes of interest (the hydroxyl group tends to deprotonate, potentially resulting in different conformations if the pH is not appropriate due to the release of a proton). In this way, splitting of the analyte peaks in the chromatogram is avoided due to the equilibrium that would occur between the protonated and deprotonated forms.

All students answered all questions proposed and passed the experimental reports submitted; in fact, over 95% of the students received grades higher than 7 over 10 in all cases. This indicated that they all had understood the main objectives of the practice correctly, namely the most important chromatographic concepts and the influence of parameters on the extraction of bioactive compounds of interest. The main mistakes detected were related to data interpretation, as certain students failed to recognize outliers. Consequently, the resulting outcomes were inaccurate, leading to flawed conclusions regarding the optimal conditions. Finally, it is worth noting the fact that the analytical results obtained agreed with the known value of the sample that was also evaluated, that is with the value that appeared on the labeling of the commercial container of spicy paprika (it is very important to take into account that the content of these compounds can be affected by several factors, including genotype, water availability, light, temperature, climatic and growth conditions, cultivation techniques, or maturity stage). Once this was demonstrated, in addition to having carried out the practical situation correctly, they knew how to process the collected data to obtain the analytical results. This feedback indicated that the learning objectives and instructional goals were met.

The results of this laboratory practice reinforce the importance of experimental work carried out in teaching laboratories, as they play a fundamental role in the construction of scientific knowledge. Well-designed laboratory practices provide an excellent opportunity to establish connections between theory and practice, that is, the real-world application of chemical science [36]. A dual approach (classroom learning alongside laboratory exercises with real-world problems) provides students with a deeper understanding of the practical utility of multiple analytical techniques for solving real-world problems during chemical analysis. Laboratory sessions allow students to reinforce theory directly through experience and develop conceptual depth. However, often due to a lack of time or the availability of materials, it is not easy to design a practice where students have some freedom and can put into practice the abstract concepts studied theoretically with their own experimental results, making them more concrete and visual [37].

Given a lower instructor–student ratio and a less formal environment, the laboratory is a conducive place for learning and provides opportunities for students to practice behaviors like scientists, such as asking questions, analyzing and interpreting data, or constructing explanations [38]. Furthermore, the informal atmosphere and smaller number of students allow them to feel freer for social interaction, both among themselves and with the professor, and less intimidated when asking questions, resulting in healthier learning and a more meaningful understanding of scientific concepts [39]. Therefore, it is important to leverage this environment so that students take a more active role in their decisions, truly fostering their skills, and not merely following established protocols.

This type of unsupervised laboratory practical exercise (meaning student-led but with the availability of a professor for any questions or needs), in addition to solidifying the theoretical concepts covered in class and acquiring technical skills, is a valuable tool for stimulating the acquisition of students' critical thinking skills, problem identification, and problem-solving abilities that mimic real-life challenges. These exercises can foster increased motivation, interest, and self-confidence, leading to improved performance. They also contribute to the development of scientific attitudes and the innovative spirit of students in their future careers [40].

However, the main limitation of implementing this practice in any university laboratory is time, as it is a rather complex technique that encompasses many aspects, thus requiring a focus on the most important fundamentals. Additionally, there is the acquisition and maintenance of chromatography equipment, which can be costly, and the complexity of the technique for students with little experience.

The laboratory sessions presented in this article serve as an example of how a classic and robust tool, which has been used for a long time in the (bio)chemistry laboratories of many universities, can be 'reformed' by considering the principles of interdisciplinary and research-based learning approaches [41]. One of the competencies related to Sustainable Development Goals (SDGs) in this course involves critically contextualizing knowledge, and establishing interrelations with social, economic, and environmental issues. Thanks to this simple laboratory practice, the proposed premises are fulfilled, including the minimal preliminary preparation required, the analysis of a sample commonly consumed today, cost-effectiveness, low generation of waste (only small aqueous samples are used), calibration with different types of standards, short analysis times, and low solvent consumption [42]. Additionally, this practice promotes the use of instrumental analysis that aligns with current sustainable development goals, thus contributing to the establishment of what Agenda 2030 outlines as Education for Sustainable Development [43], promoted by the Conference of Rectors of Spanish Universities. More specifically, this practical session has fostered the development of transversal competencies, such as critically contextualizing the knowledge to be acquired, thereby establishing social interrelationships and also the sustainable use of resources in preventing negative impacts on the natural and social environment. All these features make the current HPLC protocol for quantifying capsaicinoids in paprika samples an environmentally responsible technique for analytical chemistry and instrumental analysis laboratories and suitable for both individual and collaborative work.

4. Conclusions

Based on the results obtained, it can be concluded that the proposed practice, aimed at reporting the total spicy-content data to label a batch of spicy peppers, satisfactorily meets the objectives and competencies pursued in an instrumental analysis practice. It is a simple, short-duration, low-cost practice that allows students to apply and complement the theoretical knowledge acquired.

The implemented methodology represents a successful approach, as it allows students to gain a better understanding of liquid chromatography applied in analytical measurements starting from a real-world problem. The fact that they had to work through the different stages of the analytical process, from problem identification and sample collection to the final result, has helped them contextualize and gain a holistic view of the importance of instrumental analysis. Furthermore, it has fostered the acquisition of competencies, such as the importance of critical data analysis, strengthening the assimilation of concepts, and applying theoretical knowledge to the analysis of a commercial product. On the other hand, the low generation of waste has allowed contextualizing the economic, social, and environmental issues pursued with the SDGs (Sustainable Development Goals).

These significant pedagogical aspects were confirmed through the evaluation of the laboratory reports, where students achieved the competencies established for this procedure, with grades higher than seven in all cases. Finally, by working in groups and sharing common objectives, the students learned firsthand the benefits of teamwork, which is often a necessity in scientific research.

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Article

A Generic Multilevel Structure for Educational Escape Rooms

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Abstract: The use of active learning activities for evaluation purposes has been reported to improve results in all areas within the education field. In this paper we describe a generic multilevel structure for educational escape rooms, along with a use case where such a design was applied for assessment in a course within the STEM area. Furthermore, a project-based learning activity was also added to complement that assessment. The results obtained expose an increase in both academic performance and success rate, where the percentage rises in both cases go in line to the literature. Additionally, a high level of engagement was measured during those active learning activities, which is reported to lead to better performance and improved learning. Hence, this high engagement seems to be the primary source of the increments experienced.

Keywords: active learning; escape room; gamification; innovative education; project-based learning

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1. Introduction

Active learning is an alternative paradigm to traditional lecturing, where a more student-centered approach is taken [1]. This way, students get a more proactive role in their education, while the teacher's role turns into a facilitator in their learning process [2]. Furthermore, extensive research states that scholars learn more if they get actively engaged in a classroom environment than if they are in a passive lecture condition [3].

Different approaches may be followed to deploy the active learning paradigm, such as flipped classrooms, serious educational games, project-based learning or team-based learning, in order for students to acquire the expected key competences [4]. However, in the active learning realm, educational escape rooms are one of the most appreciated activities by students, as they get embedded into a game experience, while they are actually undertaking a learning activity [5].

In this sense, educational escape rooms may be seen as competitive activities looking for increasing students' participation and motivation, which may be held as either multi-player or single-player competitions [6]. Also, they could be organized in many ways, such as moving through different locations in the learning premises, interacting with physical objects in the classroom, or setting it up on a learning management system [7].

In this paper, a generic multilevel structure for educational escape rooms is presented, which may be used as a backbone to implement escape rooms in any education field. Furthermore, a use case of creating and running this kind of specific type of educational escape room as an evaluation activity is presented in the context of a course of an engineering degree at College, as well as an additional project-based learning activity. In addition to the boost in results achieved, a measurement of the engagement level of the students has also been performed [8], which is a primary source of enhancing academic performance when the magnitude measured is high enough [9].

The rest of the paper is organized as follows: Section 2 presents the design of a generic multilevel structure for escape rooms, Section 3 shows the methodology, Section 4 exhibits the results, Section 5 exposes the discussion, and Section 6 draws conclusions.

2. A Generic Multilevel Structure for Escape Rooms

Educational escape rooms may be defined as a sequence of tasks to be accomplished within a time-constraint interval [10]. Regarding pedagogy, students build up their own knowledge while they move along the escape room, as they get involved in it [11]. As a matter of fact, there is a revised framework of Bloom's Taxonomy adapted to educational escape rooms, where the 6 categories of cognitive processes are described, such as 'remember', 'understand', 'apply', 'analyze', 'evaluate', and 'create' [12].

On the other hand, educational escape rooms are composed of a series of puzzles, which could be organized in different ways. For instance, open path structure offers a collection of concurrent puzzles to get to the final stage, whilst linear-path structure presents a string of puzzles to get there. Likewise, a path-based structure may be seen as a combination of the above, where a collection of redundant linear paths are available. Moreover, any hybrid combination is available, such as a pyramid structure [13].

In this sense, the structure proposed herein is a sequence of linear-paths, where each path must be cleared before taking up the next one [14]. This way, it is possible to dedicate each linear path to a different generic domain, which could be considered as a specific chapter or a particular didactic unit. Therefore, the generic multilevel structure proposed allows to evaluate the knowledge, skills and attitudes acquired.

Hence, the escape room proposed is composed of a series of sequential levels, which are the linear-paths, such that each level is formed by a string of sequential stages. This type of structure could be compared to a bidimensional array or matrix [15], where its rows are considered as levels and its columns are seen as the stages forming each level, where all stages within a given level must be traversed before getting into the next level.

This structure for escape rooms permits to take a series of exams whose questions are randomly taken out of a question bank related to a certain chapter, including multiple choice questions, as well as fill in the blank questions, and also calculated questions with random variables. The target is to get each exam done with the highest marks, as those determine the number of hops away taken in the escape room.

A full class session is dedicated to run a given escape room, and scholars may participate in groups, or otherwise, they could do it individually. In any case, the ultimate goal is to take the series of exams in the shortest possible time because the overall mark obtained when finishing the escape room will depend on the time spent to clear it. Hence, students are meant to apply the knowledge, skills and attitudes they learnt in a given chapter to get a good performance in the evaluation with escape room.

As we are based in Spain, we adjusted the structure of the escape room to the Spanish grading system [16], which ranges from 0 to 10 and the passing grade is 5. This way, we set up each exam with 10 questions, where each one is evaluated as either right or wrong, such that the former accounts for 1 point and the latter stands for 0 points.

Therefore, if the outcome of a particular exam is lower than the passing grade, then it implies no movement in the escape room. On the other hand, if the outcome equals or overcomes the passing grade, then it implies a movement in the escape room, whose magnitude is exposed in Table 1. However, as each level is independent from the other levels, it is no possible to go further than the beginning of the next level, so the extra hops obtained will get lost.

Table 1. Hops away assigned to the outcome of an exam.

Score	0	1	2	3	4	5	6	7	8	9	10
Hops away	0	0	0	0	0	1	2	3	4	5	6

As top marks account for 6 hops away, each level has been designed with 6 stages, as seen in Figure 1, where 4 levels are shown just as an instance. This way, if a group is at the initial stage of a given level and it gets the top score in an exam, then the group gets moved to the initial stage of the next level [17]. This allows to traverse a whole level with just one move, which results in the possibility of traversing the whole escape room with just 4 moves if a group is able to obtain 4 exams in a row with top marks.

If top marks are not attained at the initial stage of a level, then the movement achieved will lead the group to a certain stage within the same level, thus the following movement might take the group as far as the initial stage of the next level, such that the remaining hops obtained will not be taken into consideration as they will be discarded.

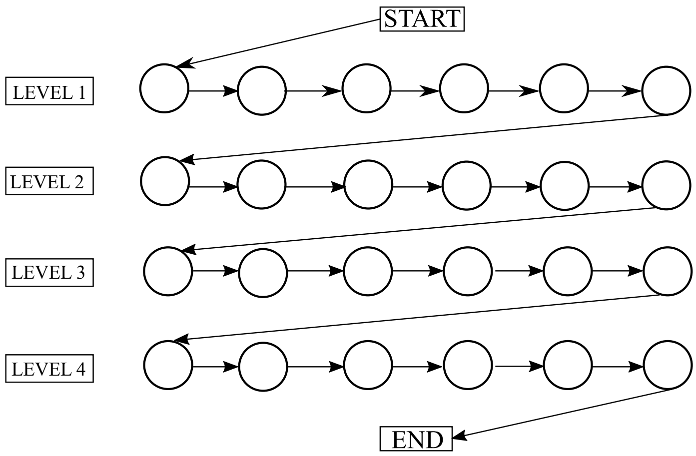

Figure 1. Flow chart in the escape room proposed.

On the other hand, the goal is to clear the escape room as soon as possible, such that top marks are awarded to all groups doing it within the 60% of the session time, whilst passing marks are awarded to the groups doing it by the end of the session, namely 100% of the session time. Furthermore, intermediate marks will be granted according to the time elapsed to finish the escape room, such as a grade of 9 for doing it before the 70% of the session time, a grade of 8 for the 80%, a grade of 7 for the 90%, and a grade of 6 for the 95%. Additionally, failing marks are granted to those not being able to finish it.

However, in case there are students in the course with learning disabilities who will probably require a longer time limit, it is to be taken into consideration that after the end of the session where students carry out the escape room, they have to attend another session related to another course, so it is not suitable to extend the time devoted to the escape room. Therefore, the most convenient solution in those circumstances is to assign those specific students an escape room with a lower amount of levels than their peers, such that they may have enough time to finish the shortened version of the escape room.

3. Methodology

Once the structure proposed has been duly exposed, then a use case is presented. This use case is set up in a course at college related to architecture and technology of computers. This way, each level within the structure is devoted to a specific didactic unit within the curriculum, whereas the puzzles composing each level are related to answering questions or solving tasks about the corresponding didactic unit assigned to that level. Besides, the marks achieved in each puzzle are related to how much players get moved ahead within a level in the escape room.

In this context, the evaluation of this course was done though an escape room of 3 levels, because the course was composed of 3 different didactic units, where the first one was devoted to binary arithmetic, the second one was dedicated to the building blocks of a computer, and the third one was committed to assembly language.

3.1. Design for the Escape Room Proposed

The design of the escape room proposed is a multilevel linear path, where students are facing a challenge within a story board to be sorted out on an individual basis. To start with, the teacher explains the background of the story, which is called “Save the Earth”. In order to embed students into the plot, some epic music is played non-stop out of pixabay website, which offers music tracks without royalties. Furthermore, some royalty-free pictures from the same website are displayed on the interactive whiteboard in order for the students to feel more integrated into the story.

At the beginning of the escape room, an introduction is given for the students to understand the critical situation where they are immersed into. This background is exposed by the teacher to the students, as well as it is found when first accessing the escape room in the Moodle platform of the university. Basically, it is told that we are in the year 2050, where conditions are tougher than today. In that context, a huge meteorite is coming straight to Earth and the only chance for the planet to survive is to launch a space rocket with a brand-new laser system so as to destroy the meteorite before hitting the planet and destroy everything completely.

However, one key piece in the laser system is missing, which has been developed at our University. Hence, the mission is to get into our campus and find that piece as soon as possible. Nonetheless, the change in climate conditions during recent years has brought up new and dangerous species regarding flora and fauna, thus the whole path through the campus university is as tough as ever, because it is full of dangers.

The mission is divided into three stages, which are considered as three different levels, each of those composed of a number of states to be traversed in a sequential manner, namely 6 stages. In order for each student to advance through those steps, a test attempt needs to be made, where each attempt consists of a 10-question quiz to be done individually. The marks obtained at each attempt indicate the magnitude of that movement, as it has been previously described, such that the higher the grade obtained in a test, the larger the move to be made within the current level of the escape room.

Each level must be done on an independent basis, in a way that the stages included in each level must be cleared before starting with the next level in the next attempt. Eventually, the escape room finishes when the last level is cleared, although the aim for all students is actually to finish the game on their own. The first level is devoted to move through the University Campus to reach the University Rector's building. The second level is dedicated to move through the University Rector's building to get into the University Rector's office. The third level is committed to the University Rector's office, where the missing piece is located right in the last puzzle, also known as meta-puzzle.

In summary, the main goal of the escape room is to evaluate students about the knowledge, skills and attitudes they acquired during the course, although such an assessment is done through an active learning activity, as opposed to a traditional written exam. However, the use of an escape room for evaluation purposes also portrays a fun part due to the gaming environment induced, which acts as a complement of the evaluation part.

This could be broken down into two key aspects, such as the competitivity among players and the layout of the activity. Focusing on the former, the fun is in the motivation in order to compete with the rest of players so as to get ahead of them in the activity, which is boosted by the gaming environment. Centering on the latter, the fun is in the layout of the activity, such as playing a specific music during the competition, or wearing fancy dresses for the competition according to the curriculum being assessed.

Regarding the presentation of the escape room to the students, at the beginning of the session the teacher gets into the classroom dressed with a fancy jacket and a piece of apocalyptic music starts out. After a few seconds, the teacher exposes the background of the story, such that a big meteorite is about to hit the Earth, which is shown in the interactive board of the classroom, and our only option to avoid the collision is to find the missing piece of a laser system. This piece is located in our University and it will be found at the end of the escape room, so students must clear it as soon as possible in order to save the Earth.

3.2. Evaluation of the Course

The evaluation of this course related to Architecture and Technology of Computers was done through the aforementioned educational escape room, which accounted for two thirds of the final mark. As stated above, the marks assigned to each student depended on how long each student took to clear the three levels proposed, where each one was dedicated to one of the didactic units within the course.

On the other hand, the other third of the final mark was assigned through the development of a project in assembly language, which had to be exposed in a specific class session as a pitch presentation. Hence, this project-based learning activity was composed of 2 parts, such as the programming part and the presentation part, where the former was done by designing and developing the code to meet the specifications of the project, and the latter was done by preparing and delivering the presentation. Each project had to be carried out on an individual basis, whereas students had to assess all projects, including their own ones, on a peer review basis. This way, the pressure to get a great performance in the escape room was not so critical, because they could improve their marks with this project-based activity.

4. Results

First of all, it is to be mentioned that there are 25 students in the course in the current academic year, whereas there were 24 in the same course in the previous academic year. Hence, both amounts of scholars are comparable, which allows to confront the grades achieved in both years. In this sense, it is to be remarked that an active evaluation approach was taken in the current year, by means of using an escape room and a project-based learning activity. On the other hand, a traditional evaluation approach was followed in the past year, by means of using a traditional written exam.

4.1. Escape Room

Regarding the escape room, Table 2 exhibits the amount of students within the different scores used to assess the performance in the escape room, as explained above. In this sense, it is to be said that students not completing the escape room failed the activity, although they were awarded 4 points if they got to clear two levels, or otherwise, they were awarded 2 points if they got one level cleared, whilst they were awarded 0 point if they did not achieve to clear any level whatsoever.

Table 2. Outcome of the educational escape room proposed.

Performance Obtained	Number of Students	Marks Achieved
Completed within the 60% of the session	3	10
Completed within the 70% of the session	3	9
Completed within the 80% of the session	4	8
Completed within the 90% of the session	5	7
Completed within the 95% of the session	3	6
Completed within the 100% of the session	4	5
Not completed, with 2 levels cleared	2	4
Not completed, with 1 level cleared	1	2
Not completed, with 0 levels cleared	0	0

The descriptive statistics referred to the results obtained are summarized in Table 3.

Table 3. Descriptive statistics of the educational escape room proposed.

Type	Statistic	Value
Centralization	Average	6.88
	25th percentile	5
	50th percentile	7
	75th percentile	8
Dispersion	Variance	4.36
	Standard deviation	2.09
	Coeff. variation	0.30

4.2. Project-Based Learning Activity

With regards to the project-based learning activity [18], the pitch presentation made by students to expose their projects had to be assessed by a construct composed of 6 items. Those items are exhibited in Table 4, which are classified in 2 categories, such as programming and presenting, where 3 items are included in each one. Basically, the first category is devoted to the coding structures used, the clarity of the code employed, and the comments made along the code, whilst the second category is dedicated to explain the functionality of the code presented, the execution of that code, and the communication skills shown when making the pitch presentation.

Table 4. Items within the construct to evaluate the project-based activity.

Category	ID	Item
Programming	Q1	Coding skills
	Q2	Code clarity
	Q3	Code comments
Presenting	Q4	Functionality
	Q5	Execution
	Q6	Communication skills

Prior to exposing the items, also known as questions, in the construct for students to evaluate the different projects on a peer-review basis, a panel of 5 experts rated each question according to 2 dimensions, namely the construction of each item and its clarity, in order to assess the validity of the construct [19]. Those ratings were made by means of a specific construct for those experts with 4-point Likert-type scales, where the value of 1 was assigned to 'strongly disagree', the value of 2 was tied to 'disagree', the value of 3 was associated to 'agree' and the value of 4 was linked to 'strongly agree'. Table 5 exhibits the averages of each item, as well as the average for each dimension considering all items, along with the overall average.

Table 5. Average marks assigned for the questions according to the dimensions defined.

	Q1	Q2	Q3	Q4	Q5	Q6	Dimension Average	Overall Average
Construction	4.0	3.8	4.0	3.6	3.6	4.0	3.833	3.783
Clarity	3.8	3.8	3.6	3.4	3.6	4.0	3.733	

Once the overall average has been obtained, then the Aiken's V test may be performed, which accounts for 0.928. This value is higher than the most common cutoff marks, such as the Aiken's benchmark, which is 0.87 [20], the Charter's benchmark, which is 0.70 [21], and the Cicchetti's benchmark, which is 0.50 [22]. This way, different degrees of agreement may be appointed accordingly, either tougher or looser. Therefore, as the value obtained in the Aiken's V test is greater than the benchmark established, which is the case for the three thresholds quoted, it may be concluded that the construct with the items selected has been validated by the panel of experts. Hence, at that point, the construct was ready to be presented to the students for peer-review evaluation.

Regarding the results of the peer-review assessment, it is to be noted that the ratings of each item belonging to any of both dimensions were done through another construct for students with 5-point Likert-type scales, where the value of 1 was assigned to 'strongly disagree', the value of 2 was tied to 'disagree', the value of 3 was associated to 'neither agree nor disagree', the value of 4 was linked to 'agree', and the value of 5 was bound to 'strongly agree'. Additionally, it is to be said that the categories defined above, namely programming and presenting, are now considered as dimensions in this construct to measure the students' results. Table 6 displays the most common descriptive statistics extracted from those results.

Table 6. Descriptive statistics of the results of the project-based activity proposed.

Type	Statistic	Programming Dimension	Presenting Dimension	Overall
Centralization	Average	4.61	4.51	4.56
	25th percentile	4	4	4
	50th percentile	5	5	5
	75th percentile	5	5	5
Dispersion	Variance	0.32	0.33	0.33
	Standard deviation	0.57	0.58	0.57
	Coeff. variation	0.12	0.13	0.13

The reliability of the results obtained was measured according to the Cronbach's alpha [23], as shown in Table 7. The benchmark for an acceptable level of reliability according to the value of Cronbach's alpha is 0.70 [24], which also accounts for the internal consistency of the data considered in both dimensions, as well as a high level of correlation among them. This is the case herein, as not only the overall value obtained is above that benchmark, but also the values referred to the dimensions are also higher than the benchmark.

Table 7. Reliability of the results by means of Cronbach's alpha.

	Programming Dimension	Presenting Dimension	Overall
Cronbach's Alpha	0.738	0.762	0.801

Nonetheless, the degree of correlation between dimensions has also been measured by calculating the Pearson's correlation coefficient and the Spearman's rank correlation coefficient between the data belonging to both dimensions. Both coefficients are greater than 0.50, which usually implies a high level of correlation [25], as seen in Table 8.

Table 8. Correlation of the results belonging to programming and presenting dimensions.

Type of Correlation	Value
Pearson's correlation coefficient	0.504
Spearman's rank correlation coefficient	0.536

4.3. Measurement of the Level of Engagement

The level of engagement during both active learning activities, namely the educational escape room and the project-based learning activity, was measured through the ISA engagement scale. This is a 7-point Likert-type construct with three dimensions, namely intellectual, social and affective, where each one contains three standard items [26]. The ratings assign a value of 1 to 'strongly disagree', whilst a value of 2 is assigned to 'disagree', and a value of 3 is associated to 'partially disagree'. Also, the ratings assign a value of 4 to 'neutral', whilst a value of 5 is assigned to 'partially agree', whereas a value of 6 is associated to 'agree', and a value of 7 is tied to 'strongly agree'.

Therefore, the goal in this construct is to achieve an average of at least 6 in all dimensions, as this is the value corresponding to 'agree', which will lead to an overall value of above 6 as well. Furthermore, this scale was originally thought for employees working in organizations, although it may be extrapolated to other fields, such as education [27]. Table 9 displays the items assessed in the ISA engagement scale, along with their corresponding dimensions.

Table 9. Items organized by dimensions to evaluate the level of engagement achieved.

	Dimensions	Items
1	Intellectual	Q1: I focus hard on my work. Q2: I concentrate on my work. Q3: I pay a lot of attention to my work.
2	Social	Q4: I share the same work values as my colleagues. Q5: I share the same work goals as my colleagues. Q6: I share the same work attitudes as my colleagues.
3	Affective	Q7: I feel positive about my work. Q8: I feel energetic in my work. Q9: I am enthusiastic in my work.

Table 10 exhibits the descriptive statistics corresponding to each dimension and overall, according to the results collected in the ISA engagement scale. On the other hand, the reliability of those results related to the level of engagement was measured by calculating the Cronbach's alpha, whose outcome is exhibited in Table 11.

Table 10. Descriptive statistics of the engagement results of the project-based learning activity proposed.

Type	Statistic	Intellectual Dimension	Social Dimension	Affective Dimension	Overall
Centralization	Average	6.51	6.64	6.69	6.61
	25th percentile	6	6	6	6
	50th percentile	7	7	7	7
	75th percentile	7	7	7	7
Dispersion	Variance	0.58	0.26	0.22	0.35
	Standard deviation	0.76	0.51	0.46	0.60
	Coeff. variation	0.12	0.08	0.07	0.09

Table 11. Reliability of the engagement level results by means of Cronbach's alpha.

	Intellectual Dimension	Social Dimension	Affective Dimension	Overall
Cronbach's Alpha	0.925	0.736	0.788	0.703

The values of reliability attained are higher than 0.70, which implies an internal consistency of data, along with a high level of correlation among dimensions. This point was reinforced by calculating the correlation coefficients according to Pearson and Spearman, as displayed in Table 12.

Table 12. Correlation of the engagement results among dimensions.

Type of Correlation	Intellectual vs. Social	Intellectual vs. Affective	Social vs. Affective
Pearson's correlation coefficient	0.562	0.547	0.636
Spearman's rank correlation coefficient	0.571	0.531	0.662

5. Discussion

With respect to the data analysis procedure, it is to be distinguished among the data collected out of the escape room, which have been presented in Section 4.1, the data compiled from the project-based learning, which have been exposed in Section 4.2, and the data referred to the measurement of the level of engagement, which have been displayed in Section 4.3. Moreover, all data have been anonymized and aggregated, such that it is not feasible to associate any single student with any kind of data.

On the one hand, data extracted from the escape room are aggregated according to the time elapsed for each student to finish it, where data are aggregated by time intervals. Then, descriptive statistics are applied to such data in order to find out the measurements of centralization most commonly used, such as the average and the quartiles, and the measurements of dispersion most commonly used, such as the variance, the standard deviation and the coefficient of variation.

On the other hand, data extracted from the project-based learning come from two different sources, such as those coming from the panel of experts in order to validate the peer-review construct and those coming from the students to perform the peer-review evaluation of the projects. With respect to the former, just the overall average is necessary, as it is mandatory in order to find out the Aiken's V test, which validates the construct.

With regards to the latter, data are aggregated by the discrete values obtained, and in turn, descriptive statistics are applied to the dimensions proposed with such data in order to calculate the most common centralization and dispersion measurements, as exposed for the escape room. Furthermore, the Cronbach's alpha is calculated for each dimension in order to assess the reliability of each dimension and overall, as well as the Pearson's correlation coefficient and the Spearman's correlation coefficient are used to calculate the correlation among dimensions, which reinforces the information given by the Cronbach's alpha.

Eventually, data extracted from the measurement of the level of engagement with the ISA engagement scale is compiled and the same data analysis procedure is applied as the one described for the data collected for the peer-review evaluation of the project-based learning.

Regarding the results obtained in the escape room, in Table 3 was quoted an average value of 6.88 out of 10, which is the the top mark in the Spanish grading system. Furthermore, the first quartile value is 5, the second one is 7 and the third one is 8. This represents that most of the students got to finish the escape room proposed, as the first quartile is 5, and also over half of them did it ahead of time, as the second quartile is 7. Actually, only 3 out of 25 students were not able to do it, which represents just a 12% of the overall scholars. Also, the coefficient of variation is 0.30, which is just the boundary of a moderate variation of data with respect to the average, that being seen as acceptable.

Considering just the escape room, and comparing the academic performance and the success rate attained this current academic year with respect to the previous academic year in the same course, Table 13 exposes a rise in academic performance and in success rate as well. On the one hand, the average grade attained in the last year was 6.25 out of 10, whilst in the current year it was 6.88 out of 10, thus resulting in a rise of 10% in academic performance. On the other hand, the success rate in the last year was 19 out of 24 students, namely 0.77, whereas in the current year it was 22 out of 25 students, namely 0.88, thus accounting for a rise of 14% in success rate.

Table 13. Rise in academic performance and success rate, considering only the escape room.

	Previous Academic Year	Current Academic Year	Variation Ratio	Percentage Rise
Academic performance	6.25 out of 10	6.88 out of 10	6.88/6.25 = 1.10	10%
Success rate	19 out of 24 = 0.77	22 out of 25 = 0.88	0.88/0.77 = 1.14	14%

With respect to the outcome attained in the project-based learning activity, the first thing to be noted is that a construct for evaluation purposes was built up with 6 items. In turn, this construct was assessed by a panel of 5 experts on the grounds of 2 dimensions for each of its 6 items, namely its construction and its clarity. This assessment was done through ratings in a 4-point Likert-type scale, such as the overall average resulted in 3.783, which yielded a value for the Aiken's V test of 0.928. Hence, as this value is greater than any of the benchmarks considered, namely 0.87 for the Aiken's one, 0.70 for the Charter's one, and 0.50 for Cicchetti's one, then the construct got validated.

Afterwards, this construct was used for the students to rate the projects delivered, where each item had to be rated in a 5-point Likert-type scale. As exposed in Table 6, the overall average value is 4.56 out of 5, which is the top mark. However, this mark is easily converted into the Spanish grading system by just doubling it up, thus yielding 9.12 out of 10. Furthermore, the first quartile is 4, whereas the second and third quartiles are 5. This represents that most students got high marks, as the value 4 corresponding to the first quartile is associated to 'agree', whereas the value 5 is assigned to 'strongly agree'. Additionally, the overall coefficient of variation is 0.13, which represents low variability of the results obtained, which is seen as pretty trustworthy for being lower than 0.15.

Moreover, the reliability of the data obtained was measured through the Cronbach's alpha, which yielded an overall value of 0.801, whilst it accounted for 0.738 for the programming dimension and 0.762 for the presenting dimension. As values above 0.8 are considered as good, and those greater than 0.70 are viewed as acceptable, it may be said that the results obtained have internal consistency, considering the overall data as well as the data related to each particular dimension. Besides, those values account for high correlation between the dimensions considered, which was reinforced by calculating both the Pearson's correlation coefficient and the Spearman's rank correlation coefficient. In fact, both values were higher than 0.5, which are taken as high correlation.

As per the evaluation system stated above, it is to be reminded that the contribution of the escape room to the final mark of the course was two thirds, whereas the project-based learning activity accounted for the other one third. Hence, considering both activities and the different weights assigned to each one, the final academic performance attained is given in (1).

$$\frac{2}{3} \times 6.88 + \frac{1}{3} \times 4.56 \times 2 = 7.63 \tag{1}$$

Likewise, with respect of the final overall success achieved, it is to be seen that the marks achieved in the project-based learning activity were pretty high. This fact basically assured that the great majority of students passing the escape room activity got an increment in their final grades, while none of them got a final mark under the passing score. Otherwise, one of the students who failed the escape room got a final mark which overcame the passing score of 5, whilst the other two students could not make it. In short, there were 23 students out of 25 who eventually passed the course, whereas other 2 students failed.

Therefore, considering both the escape room and the project-based learning activity, and taking into account the evaluation system exposed above, it has to be compared the final academic performance and the final success rate attained this current academic year with respect to the previous academic year in the same course. In fact, Table 14 exhibits the rise in the final academic performance and in the final success rate as well.

On the one hand, the final average grade achieved in the previous year was 6.25 out of 10, whilst in the present year it was 7.63 out of 10, which stands for a rise of 22% in the final academic performance. On the other hand, the success rate in the previous year was

19 out of 24 students, namely 0.77, whereas in the present year it was 23 out of 25 students, namely 0.92, thus accounting for a rise of 19% in final success rate.

Table 14. Rise in final academic performance and final success rate, considering both the escape room and the project-based learning activity.

	Previous Academic Year	Current Academic Year	Variation Ratio	Percentage Rise
Final Academic performance	6.25 out of 10	7.63 out of 10	7.63/6.25 = 1.22	22%
Final Success rate	19 out of 24 = 0.77	23 out of 25 = 0.92	0.92/0.77 = 1.19	19%

In short, the rise in academic performance is 10% when considering just the escape room, while it is 22% when considering both the escape room and the project-based learning activity, whereas the rise in success rate is 14% in the former and 19% in the latter. At first sight, it seems clear that adding the project-based learning activity led to an increase the values attained. However, it may be argued that the distribution of the weights assigned in the evaluation system implemented could be the reason why the final figures grew. Likewise, other possible reasons might be the deployment of a peer-review system for evaluation, where students were quite generous in their assessments, or even that the further activity was not as demanding as the original one.

Anyway, according to the literature, the increment described in academic performance when implementing active learning in STEM courses is reported to be around 15% [28], whereas the increment reported in success rate is reported to be around 20% [29]. Hence, the increments achieved herein when considering only the escape room are relatively close to the figures reported, whereas the increments attained when considering both the escape room and the project-based learning activity get even closer to the values reported, although the reasons exposed before may have influenced the definitive figures achieved [30].

Consequently, sticking only to the escape room results, it may well be said that the percentage rise achieved herein, namely 10% in academic performance and 14% in success rate, could be considered to be both in line with the increments reported in the literature when applying the active learning paradigm in the field of STEM education.

With respect to the measurement of the level of engagement, which was done through the ISA engagement scale [31], the outcome exhibited in Table 10 presents average values above 6 in all dimensions, namely 6.51 for the intellectual one, 6.64 for the social one and 6.69 for the affective one. Hence, the overall average considering the 3 dimensions involved is 6.61, which is clearly above 6. This benchmark is assigned to ‘agree’ in the 7-point Likert-type scale used, and as a consequence, it could be stated that a high level of engagement has been achieved during the activities developed [32].

Furthermore, the first quartile value is 6, the second and third quartiles are both 7, which proves that most of the students taking part in the activities were highly motivated. Additionally, the overall coefficient of variation is 0.09, which represents low variability of the results obtained, which is seen as pretty trustworthy for being lower than 0.15. In addition to it, the coefficient of variation corresponding to all dimensions were also lower than that benchmark.

Besides, the data reliability was calculated by means of the Cronbach’s alpha, which accounted for an overall value of 0.703, while it resulted in 0.925 for the intellectual dimension, 0.736 for the social one, and 0.788 for the affective one. As those values are all above 0.7, they are considered as acceptable, even though the value attained in the intellectual dimension is greater than 0.90, which is viewed as excellent. Hence, it may be said that the results related to engagement have internal consistency, either the overall data, or the data related to a given dimension.

Moreover, such values account for high correlation among the dimensions considered, which was reinforced by finding out both the Pearson’s and the Spearman’s rank correlation coefficients for data corresponding to every pair of dimensions. All values attained were higher than 0.5, so it may be said that there is a high correlation among the dimensions considered.

Additionally, it has been reported that student performance in active learning contexts is geared by student engagement, which may be modeled as a product of two factors, such as student motivation and active learning experiences [33]. In other words, high motivation in active learning contexts leads to high engagement, which in turn leads to better performance and improved learning, which is the ultimate goal [34].

As a final note, it is to be reminded that the course where the escape room and the project-based learning activities where implemented as an active evaluation scheme had 25 students, so the sample size of this study is limited to these scholars. It might be considered that this sample size is too small to undertake this kind of refined statistical analysis, even though it was done in order to be as rigorous as possible with the conclusions achieved out of the results presented in spite of the small sample size, as those conclusions could be useful and extrapolated to similar courses.

In addition to it, there are other research studies in the literature in the education field with the same sample size dedicated to different areas, such as quantum physics [35], mathematics [36], technology [37], or physical education [38].

6. Conclusions

In this paper, a generic multilevel structure for educational escape rooms is proposed. Basically, the layout suggested is a sequence of linear paths, such as a given path must be cleared before starting the following one. This setup allows to dedicate each path to a different didactic unit, chapter, or issue. Therefore, this design could be used in any educational areas within humanities, social sciences and STEM education.

This instance of escape room was used as an evaluation tool in a course devoted to architecture and technology of computers. Such a course was composed of three didactic units, hence the escape room was designed with three levels, where each one was dedicated to a specific didactic unit. In addition to it, a project-based learning activity was also proposed, whose assessment was done on a peer review basis, such that the escape room contributed with two thirds of the final grade of the course, whereas the project-based learning activity accounted for the other third.

Comparing the evaluation of the same course in the previous academic year, where traditional evaluation was carried out, and in the current academic year, where an evaluation based on an active learning approach was undertaken, it happens that a rise in both academic performance and success rate has been detected. Specifically, if only the escape room is considered, then the rise in the former was 10%, whereas the rise in the latter was 14%, which are not far away from the figures reported in the literature.

On the other hand, if both the escape room and the project-based learning activity are considered, according to the evaluation system exposed above, then it occurs that an increase in both academic performance and success rate is spotted as well. Specifically, the rise in the former was 22%, whilst the rise in the latter was 19%. Those values get closer to the figures reported in the literature, even though the calculation of those figures are conditioned by different factors, such as the distribution of weights assigned to the different activities, or the use of a student-centered assessment as opposed to a teacher-centered assessment.

Additionally, the level of engagement was also measured regarding both evaluation activities, which resulted in a high level of engagement according to three dimensions, such as intellectual, social and affective. According to the literature, high engagement leads to better performance and improved learning, hence it seems that the high level of engagement experienced in the active learning activities proposed is the primary source of the rise in both academic performance and success rate.

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Abbreviations

The following abbreviations are used in this manuscript:

ICT	Information and Communication Technologies
IP	Internet Protocol
IT	Information Technology
PBL	Project-Based Learning
SDL	self-directed learning
SEG	Serious Educational Games
STEM	Science, Technology, Engineering, Mathematics
TBL	Team-Based Learning

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education sciences

Article

The Possible Impact of Department Teaching Culture on Teaching Styles of New Teachers: A Case Study of a Swedish University Department Focused on Engineering Education

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Abstract: Understanding the influence of teaching culture (tradition) within academic departments is crucial for new teachers navigating the complex landscape of higher education. This paper investigates the possible impact of the department's teaching culture on the pedagogical approaches of new teachers, forming their teaching style, concentrating on insights gathered from interviews with experienced colleagues in a Swedish university department with a focus on engineering education. By exploring the department's teaching traditions and identifying potential challenges faced by new teachers, this study offers valuable insights into enhancing teaching styles and fostering student engagement. Drawing upon both experiential knowledge and insights from pedagogic literature and courses, the authors provide practical strategies to overcome obstacles and promote operative teaching practices. Ultimately, the outcomes of this study aim to empower new teachers to create enriching learning environments that promote student motivation, engagement, and overall academic success, aligning with the findings of existing literature on pedagogy and student learning outcomes.

Keywords: teaching culture; new teacher; challenges; teaching style; enhanced and constructive learning; work–life balance; engagement

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1. Introduction

Operative teaching practices are fundamental in higher education for creating engaging and enriching learning environments. Central to this endeavor is the examination of departmental teaching cultures, which significantly influence the pedagogical approaches adopted by faculty members, which can form their teaching style. Department culture can be defined as the conditions which may support, inhibit, and affect its faculty members in terms of research and teaching [1]. Teaching style is defined as "consists of a teacher's behavior and the media used to transmit data to or receive it from the learner" [2] or as "the consistent behaviors exhibited by teachers during interactions with students throughout the teaching and learning process" [3] as well as "the implementation of philosophy; containing evidence of beliefs about, values related to, and attitudes toward all the elements of the teaching-learning exchange" [4] and generally as "approaches, activities, and techniques which a teacher uses in front of a class" [5]. Additionally, studies show how teaching culture and style within a department can impact student learning outcomes [6–10]. Literature also underscores the pivotal role of school culture and leadership in shaping teachers' responses to institutional and situational constraints and professional growth [10,11]. Understanding the professional world of teachers, especially new teachers, is crucial for better meeting their needs, expectations, and commitment to ongoing professional development. Findings from various studies suggest that new teachers often strive for personal and professional acceptance, developing coping strategies to navigate the complexities of their roles [12]. Integral to this process are department culture and leadership, which significantly influence teachers' learning and socialization, especially during the induction phase of their careers [13]. Although the significance of the induction phase and the need for support for new teachers are acknowledged, they frequently find themselves managing their responsibilities alone, without sufficient guidance and mentorship [10]. Despite this recognition, there is still a lack of attention given to the distinctive challenges encountered by new teachers, who often navigate the complexities of their profession in isolation amidst constantly evolving educational environments. Several studies have explored the influence of faculty or departmental cultures on teachers, including those by [14,15]. However, these studies have provided a broad overview. For instance, in [15], the focus is primarily on the collaborative teaching aspects experienced by novice teachers, rather than addressing all facets. Consequently, there remains a notable gap in the literature concerning a thorough investigation into how a department's teaching culture, particularly one rooted in engineering, may affect the teaching style of new teachers across multiple dimensions.

It becomes evident that gaining deeper insights into the professional world of new teachers holds immense value. By better understanding their needs, expectations, and commitments, meaningful opportunities can be provided for their continuing professional development. Consequently, this study seeks to contribute to this understanding by exploring how the teaching culture within a Swedish higher education department, specializing in teaching engineering programs, shapes the teaching styles of faculty members. The study places particular focus on the experiences of new or beginner teachers. Understanding the intricacies of teaching culture within a department is crucial for new teachers navigating the complexities of higher education pedagogy. By exploring the prevailing norms, values, and practices shaping teaching within a department, teachers can gain valuable insights into operative teaching strategies and potential challenges they may face in their teaching endeavors.

In the following sections, we will detail our methodology in Section 2, present the results and findings from interviews regarding pedagogical values in Section 3, discuss the challenges encountered by new university teachers, propose potential solutions, and draw conclusions with implications for teaching practice in Section 4. Finally, Section 5 will provide the paper's conclusion.

2. Data and Research Methodology

In our qualitative exploration of the teaching culture within a department, we employed a thematic analysis methodology, drawing upon the framework outlined by Braun and Clarke [16,17]. Braun and Clarke propose that their framework is a fundamental qualitative method that serves as a cornerstone for acquiring essential skills applicable across various analyses.

Our case study focused on a Swedish university department specializing in teaching engineering education, encompassing fields such as electrical, electronic, medical, mechanical, civil, and energy engineering. The data needed for the research was provided as conduction. Initially, we conducted semi-structured interviews with four lecturers from various engineering programs at both bachelor's and master's levels, spanning disciplines like electrical, mechanical, and civil engineering. These interviews, lasting between 30 and 60 min each, were conducted with participants selected based on criteria including their youthfulness, availability, and willingness to engage in the study. On average, the respondents possessed seven years of teaching experience. The interviews were scheduled in advance and held at locations convenient for the participants.

To provide a clearer profile of the participants, their socio-demographic characteristics are detailed in Table 1.

Table 1. Socio-demographic characteristics of the participants.

Participant ID	Gender	Age	Teaching Experience (Years)	Academic Rank	Group	Educational Background
P1	Male	38	6	Associate Prof.	Mechanical Engineering	Ph.D. in Mechanical Engineering
P2	Male	44	5	Associate Prof.	Electronic and Communication Engineering	Ph.D. in Electronic Engineering
P3	Male	39	4	Associate Prof.	Electronic and signal processing Engineering	Ph.D. in Electrical Engineering
P4	Male	43	14	Lecturer	Civil and Energy Engineering	M.Sc. in Civil Engineering (Ph.D. candidate)

During these interviews, to prepare the needed data, we posed a series of questions covering diverse aspects of the teaching culture within the department. These questions were formulated based on insights gleaned from pedagogical resources, particularly those provided through academic development courses at the Swedish university known for fostering a constructive learning and teaching environment. Topics addressed in the interviews included learning activities, course examination and evaluation practices, collegial educational discussions and professional/academic development courses, collaborative teaching and feedback practices, perspectives on teaching, addressing pedagogical challenges, cultivating an optimal learning environment, departmental characteristics, student engagement, technology integration in teaching, pre-course research practices, and views on leadership in teaching.

Following the interviews, we meticulously documented the responses provided by the participants. Subsequently, we transcribed these interviews to ensure accuracy and facilitate analysis. Upon transcription, we undertook the coding of the interview data, systematically categorizing responses based on recurring themes and concepts emerging from both our predefined questions and participants' responses. We then situated these identified themes within the context of relevant educational and pedagogical literature. Moreover, to bolster the reliability of our findings, we adhered to measures such as intercoder agreement, wherein multiple coders independently analyzed the data, ensuring consistency and validity throughout the analysis process.

Throughout the study, we adhered to ethical research standards [18], including obtaining consent from all participants and upholding fundamental ethical principles. This commitment included maintaining open communication, demonstrating a long-term dedication to the research, and safeguarding the complete confidentiality of all participant information.

3. Results and Pedagogical Insights: Understanding Departmental Culture through New Teacher Perspectives

After gathering data from interviews, this section presents the findings of the data analysis alongside pedagogical implications. These findings provide insights into the department's teaching culture from the perspective of a new teacher, aiming to identify potential teaching challenges. Altogether, the findings encompass 13 diverse topics, as outlined below.

3.1. Learning Activities

The respondents provided insights into the various learning activities employed within the department. Theoretical lectures constitute a fundamental aspect of the teaching approach, employing diverse resources such as PowerPoint slides, short educational videos sourced from platforms like YouTube, and traditional whiteboard notes. Moreover, teachers incorporate practical examples during lectures, bridging theoretical concepts with real-world applications and industry relevance. This multifaceted approach aims to enhance student comprehension and engagement with the course material.

Lab work represents another integral component of the teaching methodology, encompassing both experimental tests and computer simulations. Through hands-on laboratory sessions, students have the opportunity to apply theoretical knowledge to practical scenarios, aiming to reinforce their understanding and skill development. Additionally, project work plays a significant role in the department's pedagogical framework. By assigning industrial-based projects to student groups, teachers promote collaborative learning [19] and provide opportunities for students to tackle real-world challenges in their field of study [20]. Working within small groups fosters teamwork and enables students to benefit from diverse perspectives.

Furthermore, the inclusion of optional exercises, typically presented at the end of each lecture, intended to serve as a motivational tool for students. These exercises, which indirectly relate to final exam questions, encourage active participation and reinforce learning objectives [21]. Overall, the combination of theoretical lectures, lab work, project work, and optional exercises reflects the department's commitment to providing a comprehensive and engaging learning experience for students.

3.2. Course Examination

The examination process within the department encompasses various assessment methods aimed at evaluating student learning outcomes effectively. Lab work and project work are assessed based on a graded scale, Fail (U) or Pass (G). This evaluation approach allows instructors to assess students' practical skills and their ability to apply theoretical knowledge to real-world scenarios. Additionally, the inclusion of both lab work and project work in the assessment process reflects the department's emphasis on hands-on learning and practical application [22].

The final written exam serves as a comprehensive evaluation tool, offering multiple grading levels to distinguish student performance. Grades range from Fail (U) to Pass with Distinction (G5, over 85% of possible points), with intermediate distinctions such as Pass with Merit (G4) and Pass (G3—50% of possible points). This grading is broad enough to stay in the same group of grades if a student makes some small mistakes. Therefore, the department's examination strategy encompasses a balanced blend of assessment methods, including practical assessments, written exams, and tiered grading criteria. This holistic approach to assessment ensures that students are evaluated comprehensively across different dimensions of their learning journey [23].

3.3. Course Evaluation

Summative course evaluations serve as a pivotal feedback mechanism within the department, facilitating instructors in gauging the perceived effectiveness of their teaching methods and the overall quality of a course. The course evaluation questions were carefully designed to elicit feedback from students regarding their learning experiences and perceptions of the course. They cover various aspects such as course content, teaching approaches, and overall satisfaction. Typically comprising 5 to 15 questions, the evaluation aims to provide a comprehensive understanding of the students' perspectives. An essential component of the evaluation is a specific inquiry concerning the amount of time students have devoted to the course, which indirectly reflects the course's quality. Emphasizing the significance of time investment underscores the department's commitment to delivering rewarding learning experiences.

Conducted near the conclusion of the course, the evaluation allows students to provide feedback based on their holistic experience throughout the term. This timing ensures that feedback is pertinent and timely, empowering teachers to make informed adjustments for future course iterations. Furthermore, the evaluation process incorporates opportunities for students to provide written comments, enabling them to express their thoughts and suggestions freely. This aspect enriches the feedback process by offering additional insights and perspectives that may not be captured through structured questions alone [24].

In addition to the structured questions, students are allowed to write comments, providing valuable qualitative feedback. This open-ended approach encourages students to express their thoughts, concerns, and suggestions candidly, enriching the feedback process with nuanced perspectives and insights [25,26].

3.4. Educational Discussions

Educational discussions are vital for fostering continuous learning and professional development within the department. They provide a platform for faculty members to exchange insights, share best practices, and stay updated on emerging pedagogical trends. These discussions include frequent lunch pitches focusing on pedagogical subjects, offering an interactive space for exploring innovative teaching methods and learning from peers. New teachers are supported through assigned mentors who provide personalized guidance in navigating teaching challenges.

Additionally, dedicated pedagogical consultants offer ongoing support and guidance to faculty members, promoting continuous growth in teaching practices. Monthly meetings between program coordinators and teachers facilitate collaborative discussions on curriculum development and pedagogical innovations. Annual gatherings between student representatives and teachers provide valuable feedback for course improvement, while pedagogy seminars offer opportunities for professional development. Overall, these discussions contribute to a culture of collaboration and improvement in teaching practices.

3.5. Collaborative Teaching and Evaluations

Collaborative teaching and evaluations represent a dynamic approach employed within the department to enrich the learning experience and promote comprehensive student engagement. This collaborative framework leverages the collective expertise of multiple teachers to deliver courses and assessments, thereby enhancing the quality and effectiveness of education delivery.

A notable aspect of collaborative teaching is the integration of two to three teachers in some courses, facilitating a diverse and multifaceted learning environment. By leveraging the unique strengths and teaching styles of each teacher, collaborative teaching endeavors to provide students with a well-rounded educational experience. Moreover, dividing the course content among multiple teachers ensures comprehensive coverage and depth in the course material, which in turn can enhance student comprehension and retention [27].

Furthermore, collaborative teaching practices extend to collaborative evaluations, wherein teachers jointly assess student performance and provide feedback. This collaborative approach to evaluation not only aims to ensure objectivity and fairness but also to foster a multidimensional assessment process that captures diverse perspectives and insights. By engaging in collaborative evaluations, instructors can gain valuable insights into student progress and tailor their teaching approaches accordingly.

Moreover, the department recognizes the value of integrating external perspectives into the learning process and often invites guest speakers at the end of courses. These guest speakers, typically experts in their respective fields, offer valuable insights, real-world applications, and cutting-edge research ideas, thereby enriching the educational experience and providing students with a broader perspective on course concepts.

3.6. Perspectives on Teaching

The perspectives on teaching within the department reflect a commitment to fostering an engaging and interactive learning environment while prioritizing student-centered approaches and ongoing professional development [21]. One prevalent viewpoint emphasizes the importance of staying updated on current developments in the field of education. Teachers recognize the dynamic nature of their profession and prioritize continuous learning to ensure relevance and quality in their teaching practices. Additionally, a strong emphasis is placed on developing a comprehensive understanding of course content, driven by personal interest and thorough research prior to course delivery. This proactive approach enables teachers to deliver high-quality instruction and effectively engage students in meaningful learning experiences.

Moreover, the perspective on teaching highlights the significance of adopting a two-way learning approach, wherein both teachers and students actively contribute to the learning process. This collaborative exchange fosters critical thinking and encourages teachers to remain open to new ideas and perspectives [28]. By embracing student questions and feedback, teachers not only impart knowledge but also continuously refine their own understanding and teaching strategies.

Furthermore, teaching is viewed as a means of supporting students' learning journeys by implementing active learning activities and promoting interactive engagement. Teachers' aim is to provide a dynamic and participatory learning environment where students are actively involved in the learning process. This student-centered approach emphasizes the importance of focusing on students' actions and experiences rather than solely on their academic achievements or characteristics. Additionally, teachers are seen as leaders who guide and inspire students, fostering a supportive and empowering learning environment that promotes academic success and personal growth [21].

3.7. Anything Unthinkable (Addressing Pedagogical Boundaries)

In examining the perspectives of teachers within the department, several pedagogical boundaries have emerged as essential for maintaining a conducive and respectful learning atmosphere. These boundaries, deemed "unthinkable", are considered imperative to safeguarding the integrity of the teaching–learning dynamic and ensuring student welfare, which are outlined below.

Maintaining professional distance: Teachers recognize the significance of avoiding an "unreasonable distance" between themselves and students. Such detachment can impede effective communication, hinder student engagement, and compromise classroom management. By fostering supportive relationships while upholding professionalism, teachers can create an environment conducive to trust, respect, and collaborative learning.

Preventing discriminatory practices: The prohibition against discrimination and unfair treatment reflects the department's commitment to fostering an inclusive and equitable learning environment. Discriminatory practices not only contravene principles of fairness and justice but also erode student trust and confidence. By actively promoting diversity, equity, and inclusivity, educators can nurture a sense of belonging and empower all students to thrive academically and personally.

Respecting personal privacy: Teachers underscore the importance of respecting privacy boundaries, particularly concerning personal matters such as gender, religion, and other sensitive topics. Intruding into private domains can undermine student autonomy, dignity, and comfort, potentially leading to discomfort and disengagement. By honoring personal boundaries and fostering a culture of respect and sensitivity, teachers can create a safe and supportive learning environment where students feel valued, accepted, and empowered to participate fully in their educational journey.

Fostering an optimal learning environment: Responses underscore the importance of creating a conducive and supportive learning environment where students feel empowered to engage actively with course material and participate in classroom discussions. One common strategy highlighted is the effort to establish a friendly and inclusive class environment, which, based on the experiences of both the interviewees and the authors of this study, has been shown to improve student engagement and learning outcomes. This involves cultivating a sense of camaraderie and mutual respect among students and teachers, which encourages students to feel comfortable asking questions and challenging the teacher when necessary. By fostering open communication and promoting a culture of respect and collaboration, teachers create an atmosphere where students feel valued and motivated to actively participate in their learning journey.

Additionally, respondents emphasize the importance of providing students with a clear understanding of the course's significance and relevance from the outset. By explaining the importance of the course during the first lecture, teachers set the stage for meaningful engagement and underscore the relevance of course content to students' academic and professional development. This helps students recognize the value of their learning experience and fosters a sense of purpose and motivation in their studies.

Moreover, there is an emphasis on the importance of incorporating regular breaks into the teaching schedule to support student well-being and cognitive functioning. By implementing 10 min breaks every 45 min and offering students the option to request breaks as needed, teachers prioritize students' physical and mental health while optimizing their learning experience. These breaks provide students with opportunities to recharge, refocus, and process information, ultimately enhancing their overall engagement and retention of course material.

Consequently, by prioritizing the creation of a friendly and inclusive learning environment, emphasizing the significance of course content, and supporting student well-being through regular breaks, teachers effectively facilitate student learning and promote academic success. These strategies align with best practices in pedagogy and contribute to the cultivation of a rewarding learning experience for all students [21].

3.8. Distinctive Features of the Engineering-Based Department

One respondent highlights the department's commitment to offering engineering-based courses that prioritize problem solving and hands-on learning. This teaching culture is characterized by practical exercises and project work, which provide students with opportunities to apply theoretical knowledge in real-world scenarios. Additionally, the department emphasizes the importance of enhancing practical understanding through industry visits to companies such as Volvo, Hitachi Energy, ABB, Komatsu, and the local energy utility company. These visits offer students valuable insights into industry practices and help bridge the gap between academic learning and practical application.

On the other hand, other respondents underscore the department's focus on connecting course content to real-world problems, ensuring that examples provided by teachers are relevant and applicable to students' future careers. Moreover, the department encourages lecturers to enroll in pedagogy courses to continuously improve their teaching methods and organizational skills, reflecting a commitment to ongoing professional development. Additionally, the department facilitates knowledge dissemination and promotes a culture of continuous learning through the department's newspaper, which provides teachers with news and pedagogy materials every month.

3.9. Student Engagement

There is an emphasis on the importance of fostering open communication between students and teachers to promote student engagement. Students are encouraged to interact with teachers during breaks, providing valuable feedback and sharing their thoughts after solving exercises. Additionally, the availability of teachers beyond course periods, whether in their office or via email, ensures that students have access to support and guidance when needed. This approach to student engagement prioritizes accessibility and encourages active participation in the learning process.

Similarly, there is a highlight of the department's commitment to gathering feedback from students to enhance student engagement and improve the quality of teaching and learning. By collecting feedback from representative students at the end of each lecture, the department ensures that student voices are heard and their opinions are considered in the course development. Moreover, the department encourages students to share their thoughts after solving exercises or engaging in group activities, fostering a collaborative learning environment where student perspectives are valued.

Furthermore, the department promotes student engagement by inviting students to present material closely related to the course content. This not only provides students with an opportunity to contribute to the learning experience but also offers valuable insights for the development of future courses. By actively involving students in the teaching and learning process, the department cultivates a culture of engagement, collaboration, and continuous improvement.

Overall, the department's approach to student engagement is characterized by open communication, feedback collection, and active involvement of students in the learning process. By prioritizing student voices and creating opportunities for meaningful interaction, the department fosters a supportive learning environment where students are empowered to succeed and thrive.

3.10. Integration of Technology in Teaching at the Engineering-Based Department

The responses show the department's proactive use of technology to enrich the learning environment and support student success. Video discussions recorded on challenging course topics serve as valuable supplements to classroom instruction, accessible to students via the university-wide Learning Management System (LMS). These resources offer additional opportunities for self-directed learning and clarification of complex concepts. Furthermore, virtual meeting platforms like Zoom and Teams are employed to address student inquiries beyond regular class hours, promoting real-time communication and support.

In addition to offering video discussions and virtual meetings, the department also utilizes technology to record teacher lectures, which are then shared through the LMS. This proactive approach ensures that students have access to course materials even if they miss a class or need to review content at their own pace. By providing consistent access to recorded lectures, the department enhances learning experiences and offers valuable study aids for all students. These initiatives collectively reflect the department's commitment to leveraging technology to enrich the learning environment and support student success.

3.11. Perspectives on Course Evaluations at the Engineering-Based Department

The respondents emphasize the pivotal role of course evaluations in refining teaching methodologies and enriching the learning experience within the department. The department views course evaluations as an opportunity for formative assessment, aiming to assess teaching effectiveness and meet students' learning needs effectively. By actively soliciting feedback from students, teachers gain valuable insights into the strengths and weaknesses of their teaching methods, facilitating continuous improvement. Moreover, the emphasis on analyzing feedback to enhance positive aspects of the course and address areas for improvement underscores the department's commitment to iterative refinement and excellence in course delivery. Furthermore, the department prioritizes the utilization of course evaluations as a catalyst for course refinement and enhancement in subsequent iterations. By leveraging student feedback as a guide for course development, instructors can implement targeted changes to improve the overall learning experience. Emphasizing actionable feedback over general or personal comments underscores the department's dedication to leveraging evaluations effectively to drive meaningful improvements in course design and delivery.

3.12. Pre-Course Research Practices at the Engineering-Based Department

Respondents shed light on the research practices undertaken by teachers at the department before the commencement of courses, showcasing their commitment to ensuring the delivery of relevant and active instruction. Two sets of perspectives emerged among the interviewed teachers.

The first set highlights a comprehensive approach to pre-course research, emphasizing the importance of assessing student background knowledge and reviewing previous academic performance to tailor instruction to individual student needs effectively. By consulting with previous teachers and reviewing student grades, instructors gain valuable insights into students' prior learning experiences, allowing them to identify areas of strength and areas requiring additional support. Additionally, the focus on staying abreast of the latest developments in various course topics and publishing relevant insights in pedagogy-based journals demonstrates instructors' dedication to incorporating cutting-edge research and best practices into their teaching. Furthermore, the practice of reading pedagogy-based case reports underscores teachers' commitment to addressing common instructional challenges through evidence-based strategies and approaches. In contrast, the second set emphasizes research primarily focused on preparing well-functioning lab work examples and incorporating current market demands into the course curriculum. This approach highlights teachers' efforts to ensure that course content remains relevant and aligned with industry trends, thereby enhancing students' preparedness for real-world applications. By researching how to develop practical lab exercises and integrate up-to-date content, instructors demonstrate their commitment to providing students with hands-on learning experiences that reflect the demands of the professional landscape.

However, both perspectives underscore the importance of pre-course research in informing instructional practices and enhancing the quality of education provided at the department. Whether through assessing student backgrounds, staying informed about the latest pedagogical trends, or incorporating industry insights into course design, teachers demonstrate their dedication to delivering high-quality instruction that meets the evolving needs of students and prepares them for success in their academic and professional endeavors.

3.13. Perspectives on Leadership in Teaching

The teachers within the specific department highlight the pivotal role of leadership in teaching, emphasizing strategies used to foster student success and create a supportive learning environment. Teachers underscore the importance of leadership in achieving learning outcomes through diverse instructional methods. They provide clear goals and career guidance, helping students to navigate their academic journey and align their learning experiences with future aspirations. Additionally, teachers adapt teaching styles to accommodate diverse learning preferences, fostering inclusivity and engagement. Providing constructive feedback further demonstrates leadership, guiding students' academic progress and facilitating ongoing improvement.

Moreover, operative leadership ensures the attainment of learning objectives through diverse instructional approaches, creating a supportive and welcoming learning environment. Emphasizing critical thinking showcases teachers' commitment to promoting higher-order thinking skills and nurturing intellectual curiosity among students. Additionally, leading by example reinforces positive values and fosters a culture of integrity in the classroom.

In summary, these perspectives underscore the multifaceted nature of leadership in teaching, encompassing aspects such as goal setting, instructional innovation, feedback provision, and ethical leadership. By embracing a holistic approach to leadership, instructors can effectively guide students toward academic success and contribute positively to their personal and professional development.

4. Exploring Potential Challenges Faced by New Teachers: Practical Recommendations and Insights

Transitioning from the broader exploration of teaching culture within the department and the self-reflection of the study's authors, this section now focuses on eleven specific challenges that new teachers may encounter. The department's shift from traditional teaching to a more dynamic teaching culture involved several key changes, as follows:

From lecture-centered to student-centered: Traditional teaching often relied on lengthy lectures with limited student interaction. In contrast, the new teaching culture encourages interactive lectures, where students actively participate through discussions, questions, and group activities.

From individual autonomy to collaborative practice: While traditional teaching saw teachers working in isolation, the new approach promotes collaboration among faculty. Regular meetings, team teaching, and shared resources help build a cohesive teaching community.

From rote learning to critical thinking: Traditional methods focused on memorization and regurgitation of information. The new teaching culture emphasizes critical thinking, problem solving, and application of knowledge through practical projects and case studies.

From static to adaptive teaching methods: Traditional teaching methods remained largely unchanged over time. The new approach encourages continuous adaptation and improvement, integrating feedback from students and peers to refine teaching practices.

Despite the department's implementation of various initiatives to support faculty members, such as regular lunch pitch discussions (involve a 15-minute presentation by one of the employees within the department, followed by a question-and-answer session while enjoying lunch), pedagogy courses, collaborative teaching, and mentorship programs, certain obstacles may still arise for new teachers before they can avail themselves of these resources. In this section, we, a group comprising both new and experienced teachers, identify and discuss these challenges. We offer practical recommendations based on our own experiences as a guide for new teachers navigating the pedagogical landscape of the department.

4.1. Shyness

Shyness can pose challenges for new university teachers, impacting their ability to effectively engage with students and create a conducive learning environment. Research suggests that shyness is often linked to feelings of anxiety and social withdrawal, which can affect classroom management and vocabulary outcomes [29,30]. To empower teachers to overcome shyness and foster positive relationships, a range of strategies can be employed as follows:

Interpersonal interaction and collaboration: The teaching profession demands face-to-face interpersonal interaction and communication skills. Factors such as positive self-image and perceived popularity have been identified as significant predictors of shyness among teachers [31]. Establishing healthy relationships with students, colleagues, and university personnel is essential for fostering a conducive learning environment. Teachers who feel happier and more socially connected tend to be more efficient and contribute positively to their surroundings and society. Encouraging peer support and collaboration among teachers creates a supportive environment for sharing experiences and coping mechanisms. Actively participating in department meetings, engaging in one-on-one conversations with colleagues, and practicing preparedness before sharing thoughts are effective strategies to build confidence and overcome shyness barriers.

Customized active learning: Implementing customized active learning approaches can help mitigate the impact of shyness. By incorporating interactive teaching methods and encouraging participation through varied instructional strategies, teachers can create inclusive learning environments conducive to overcoming shyness barriers.

4.2. A Lake of Obvious Literature for the Highly Practical Course (Necessity to Take a Lab/Project-Based Approach)

When faced with a lack of literature for a highly practical course demanding a lab or project-based approach, new teachers have viable strategies at their disposal. One operative approach involves adopting a lab/project-based methodology, which enables students to actively engage with the subject matter while applying theoretical knowledge to real-world scenarios. Through hands-on activities, experiments, and projects, teachers can nurture critical thinking, problem-solving skills, and deeper understanding among students [32,33]. Moreover, supplementing the curriculum with case studies, industry examples, and guest lectures enriches the learning experience and provides practical insights. Collaboration with industry partners or research institutions provides valuable experiential learning opportunities. Moreover, strategies like flipped learning can help optimize course duration and provide students with more time for practical activities. This method has been found to positively impact student learning and course satisfaction [34]. Lastly, teachers can explore remediation strategies utilized by colleagues in similar contexts [35]. By sharing and implementing successful remediation approaches, teachers can address students' learning needs and bolster the practical aspects of the course.

4.3. Failing a High Number of Students

Efforts to understand the factors contributing to student failure, such as lack of effort or motivation, can guide teachers in developing targeted interventions. Research on the role of effort in school achievement highlights the importance of addressing student engagement and perseverance in academic tasks [36]. By encouraging students to exert effort and providing support to enhance their motivation, teachers can help students to overcome challenges and improve their performance.

Seeking support from university resources, such as coaching, mentoring, and behavior support planning programs, can be beneficial in addressing disruptive behavior and academic difficulties among students [37]. Collaborating with colleagues and educational specialists can provide new teachers with valuable insights and strategies to effectively manage classroom challenges and support student success. Considering the use of analytics systems to support higher education students can help teachers identify at-risk students and provide targeted interventions to address their academic needs. By leveraging data-driven insights, teachers can personalize their approach to teaching and learning, thereby improving student outcomes and reducing the number of failing students.

4.4. Leadership Roles

Aspiring to foster an engaging and enriching classroom environment, new university teachers can take proactive steps to enhance their leadership skills next to their role as teachers. Drawing insights from the established literature on teacher leadership, it becomes evident that strong leadership is pivotal for maximizing student development [38]. Therefore, new teachers embarking on leadership roles can greatly benefit from structured pedagogy courses, where explicit instruction in leadership strategies is provided [39]. Additionally, the importance of personal growth and identity development in assuming leadership responsibilities, which highlights the multifaceted nature of leadership development, should be emphasized [40].

Navigating the transition into a leadership role can be facilitated by following a four-phase proposed model [41]. This model serves as a guiding framework for new teachers, assisting them in preparing for leadership roles and effectively managing the associated challenges. Moreover, the significance of enhancing teachers' autonomy, communication skills, and cooperation awareness within university settings to foster leadership development is of importance [42]. By embracing these principles and actively engaging in pedagogical enhancement activities, new university teachers can establish themselves as active leaders in the classroom, ultimately contributing to the holistic growth and development of their students.

4.5. Recognizing Individual Participation of Students within Group Work or Team Assignments

To mitigate the challenge of recognizing individual participation in group work, fostering a positive relationship between students and teachers is paramount. Encouraging friendly discussions and interactions, especially during break times, can establish rapport and open lines of communication. Such informal engagements provide opportunities for students to express their thoughts, concerns, and contributions, allowing teachers to gain insights into individual involvement within group settings [21].

Moreover, the active monitoring of students during work activities enables teachers to observe firsthand the dynamics of group interactions and identify individual contributions [43]. By attentively supervising group sessions, teachers can assess each student's level of engagement, problem-solving skills, and collaborative efforts, thereby facilitating a more nuanced evaluation of individual performance.

In instances where multiple groups are involved, leveraging the expertise of Ph.D. students or researchers as dedicated supervisors for group work can further enhance individual recognition. These supervisors can provide guidance, support, and feedback to students, ensuring equitable opportunities for all individuals to showcase their abilities and contributions within the team context.

4.6. Hard to Answer/Official/Legal Requests from Students

Dealing with hard to answer or official requests from students requires educators to exercise patience and prudence in their responses. Rather than hastily consenting or declining these requests, teachers should take a step back and consider the implications of their decisions. Seeking guidance from course coordinators, program coordinators, colleagues, and legal resources available at the university can provide valuable insights and support in handling complex requests.

It is essential to recognize that consenting to students' requests may seem like the easier option, as refusal can potentially damage the teacher–student relationship and threaten the student's faith. However, teachers must prioritize educational principles, pedagogic goals, and institutional policies when making decisions. Refusal should be grounded in valid reasons, clearly communicated to students, and supported by relevant guidelines or regulations. Refusing students' requests is a common occurrence in academia, and teachers should be prepared to engage in follow-up discussions and negotiations [44]. By maintaining transparency, professionalism, and empathy in their interactions with students, teachers can mitigate potential conflicts and uphold the integrity of their teaching practices.

4.7. Best Learning Activities

Designing the best possible learning activities involves incorporating diverse and interactive elements to enhance student engagement and comprehension. Teachers should add variety to their teaching techniques to reduce the amount of mismatch that occurs between teaching style and student's learning style [8,45]. Utilizing multimedia resources such as funny slides, videos, and animations connected to course lectures can create a dynamic and enjoyable learning environment. Real-world problem-solving examples, practical projects, and seminars offer opportunities for hands-on learning and application of theoretical concepts [21,45].

Connecting lab work examples to software simulations as voluntary activities provides additional opportunities for students to reinforce their understanding and skills. Recorded video discussions and solution manuals cater to different learning preferences, offering flexibility and accessibility to course materials. Seeking continuous feedback through formative evaluation allows educators to adapt and improve their teaching methods based on student input.

Ending lectures with simple questions encourages student participation and reflection, fostering a culture of continuous improvement and self-assessment. By creating a supportive learning environment that encourages active participation and exploration, educators can optimize learning outcomes and student success.

4.8. Enhanced Well-Functioning Learning Process

To optimize the learning process effectively, it is imperative to implement various strategies. Firstly, allowing students adequate time to reflect and pose questions during lectures encourages active participation and deeper comprehension. Employing a moderate pace of speech, coupled with changes in voice tone and body language, enhances communication effectiveness. Demonstrating politeness, respect, eye contact, and attentive listening to student inquiries fosters a supportive learning environment and bridges the gap between students and teachers. Acknowledging the potential for boredom during lengthy lectures, integrating active learning techniques like reading handouts, and incorporating unplanned breaks can reinvigorate student engagement. Moreover, maintaining open channels of communication and promptly addressing student queries both in and out of class is essential for proactive course management. Lastly, focusing on clarifying fundamental concepts that may be unclear to students ensures a solid foundation for continued learning.

4.9. How to Enhance Efficiently Student Motivation and Engagement?

To efficiently enhance student motivation and engagement, a multifaceted approach can be adopted. Firstly, clearly outlining learning outcomes at the outset of each session provides students with a roadmap for their learning journey, fostering clarity and purpose. Linking lecture content and exercises to final assessments by showcasing previous exam questions incentivizes active participation and problem solving. Introducing non-addressed questions, answering them, and revisiting them in subsequent related lectures reinforces learning and encourages attentive listening. Acknowledging student knowledge and progress boosts confidence and motivation. Reviewing previous lecture material at the start of each session aids in knowledge retention and continuity. Providing timely feedback on assignments facilitates ongoing improvement and engagement. Utilizing recorded video discussions/solutions offers flexibility and accessibility to students. Additionally, allocating extra time for students to enhance their skills demonstrates a commitment to their development. Creating a safe, supportive, and friendly classroom atmosphere encourages active participation and inquiry. Sharing personal experiences and responding to questions with openness and encouragement fosters a conducive learning environment. Encouraging peer learning promotes collaboration and knowledge sharing, enriching the learning experience for all students. By implementing these strategies, educators can effectively cultivate motivation and engagement among their students, leading to enhanced learning outcomes and student satisfaction [21].

4.10. Dealing with Overactive Students

Overactive and highly distractible students can pose significant challenges in the classroom, impacting teachers' self-efficacy and the overall learning environment [46]. These students may exhibit behaviors that disrupt the flow of lessons and make it difficult for other students to focus. Managing such behaviors can be a potential stressor for teachers, affecting their confidence and the overall classroom atmosphere [47]. Therefore, teachers must have beneficial coping mechanisms to maintain a positive and productive learning environment. For this purpose, teachers can employ several strategies, as follows:

Enhance teacher self-efficacy: Teachers must prioritize enhancing their self-efficacy when dealing with challenging behaviors from overactive students [46]. This includes fostering a positive attitude towards their teaching abilities and building strong relationships with all students, including those prone to overactivity.

Understand emotional and behavioral difficulties: Remind themselves that overactive students learn differently [48] and overactivity is one of the dimensions of psychopathology [49]. This understanding helps in effectively identifying and addressing overactive behaviors in students. Teachers can then tailor interventions to provide fruitful support [50]. Moreover, it has been observed that students with overactivity, such as ADHD, respond positively when treated equally to their peers [48]. Embracing the label of ADHD as a strength rather than a negative can also contribute to fostering a positive learning environment [48].

Implement classroom management strategies: Teachers can create a conducive learning environment by establishing clear rules and procedures [51]. This includes setting clear expectations and providing regular reminders, especially for students prone to overactivity [52]. Additionally, utilizing operative time management techniques is essential to maintain focus and engagement among overactive students [51].

Strategies for engaging students with overactivity: Teachers can engage students with overactivity by giving clear expectations and rules, providing regular reminders for reinforcement. Employing strategic praise for students following rules and instructions, including those with overactive behaviors, can also be efficient [52]. Additionally, establishing routines and maintaining patience is crucial, as students with overactivity often benefit from predictability [48,52].

Collaborative approach: Sharing operative strategies with colleagues who work as teachers is crucial for supporting overactive students in the classroom. Additionally, seeking guidance from the course coordinator on handling such challenges can provide valuable insights and support. It is worth noting that one of the authors has firsthand experience with similar situations, and the solutions presented here are partly derived from their successful experiences and perspectives, supported by the existing literature.

4.11. Achieving Work-Life Balance for New Teachers

Maintaining a healthy work–life balance is essential for the well-being and effectiveness of new teachers. In practice, meeting the needs of all learning styles demanded in each class period is unrealistic [45]. Studies have highlighted the inherent conflicts faced by teachers in balancing family and professional commitments, leading to emotional dissonance, stress, burnout, and negative health consequences [53,54]. To alleviate these challenges, the following self-care strategies play a crucial role [55,56]:

Physical health: Prioritizing physical health through adequate sleep, regular exercise, and a balanced diet is essential for improving emotional well-being and resilience. Establishing consistent sleep patterns, engaging in relaxing bedtime routines, and avoiding substances like alcohol and caffeine before bedtime contribute to better sleep quality.

Social connections: Maintaining positive social connections can have long-term effects on mental health, whereas chronic social isolation increases stress levels. Actively seeking social interactions and avoiding isolation can mitigate stress and promote emotional well-being.

Cognitive training: Cognitive training techniques help to manage negative thoughts and emotions, thereby reducing stress levels. By replacing negative thoughts with positive ones and identifying and labeling emotions, individuals can modulate negative emotions and decrease stress responses.

Work-life balance strategies: To re-establish control over work–life balance, teachers can audit their priorities, establish clear boundaries, and allocate time effectively to align with personal and professional aspirations. Addressing specific issues such as long-hour cultures and excessive workloads is crucial for maintaining a healthy work–life balance.

To complete Section 4, it is crucial to highlight that in today's educational landscape, teachers from all disciplines, especially newcomers, need to possess adequate knowledge of environmental and climate change issues. The first and third authors of this study, both with backgrounds in electrical engineering, have already conducted research on how climate change affects their field [57]. They aim to utilize this expertise while instructing engineering students and developing climate change-related projects for them.

5. Conclusions

In conclusion, this study has explored the possible impact of department teaching culture on new teachers' teaching styles, considering a case study at a Swedish university focusing on engineering education. Through interviews with experienced colleagues, various aspects of teaching culture, challenges faced by new teachers forming their teaching style, and strategies to overcome these challenges have been examined. The findings highlight the importance of understanding and adapting to the teaching culture within a department, as it significantly influences the teaching style of new instructors.

The identified challenges, such as shyness, lack of literature for highly practical courses, and maintaining work–life balance, underscore the complexity of the teaching profession. However, the strategies proposed, including fostering open communication, incorporating hands-on learning experiences, leveraging technology, and prioritizing student engagement, offer practical solutions to mitigate these challenges. These methods are rooted in the experiences of engineering teachers and students, reflecting the unique dynamics of the field.

Nevertheless, the pedagogical principles underlying these strategies transcend disciplinary boundaries and can be applied across various academic fields. By embracing a student-centered approach, promoting active learning, and prioritizing continuous improvement, educators from diverse disciplines can enhance their teaching effectiveness and contribute to the holistic development of their students. Therefore, while this study focuses on the context of engineering education, its insights have broader implications for pedagogical practice across disciplines. Additionally, understanding how to effectively employ Artificial Intelligence (AI) technologies in both the teaching and learning processes for teachers and students is a contemporary challenge. Teachers need to continuously assess the extent to which AI technologies, such as ChatGPT, an advanced language model developed by OpenAI, can be utilized to enhance the educational experience. Teachers must ensure that students comprehend the genuine contributions of these technologies within a course. By recognizing the importance of teaching culture and adopting evidence-based strategies, teachers can create enriching learning environments that foster student success and engagement, ultimately advancing the goals of higher education.

The findings of this study have several practical implications for academia and practitioners. For academic institutions, understanding the influence of departmental teaching culture can inform the development of support structures and professional development programs tailored to the needs of new teachers. For practitioners, particularly new teachers, the strategies outlined in this study offer practical guidance for navigating the challenges of their early teaching careers and for fostering a positive and effective teaching environment.

While the findings of this study, conducted within a single engineering department, may offer valuable insights applicable to other engineering disciplines and certain non-engineering departments, it is important to recognize the study's limitations in generalizing beyond the specific context examined. Conducted within a single engineering department at a specific university, the findings may not generalize to other contexts. The small sample size may not capture the full diversity of experiences within the department. Additionally, the reliance on qualitative data, though rich, may be subject to subjective interpretation. Therefore, future research should expand to multiple departments and universities to enhance generalizability. Including a larger and more diverse sample would provide a broader understanding of teaching culture and challenges. Further studies could explore the long-term impact of the strategies on teaching effectiveness and student outcomes, and quantitative studies could complement the qualitative findings for a more balanced analysis.

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education sciences

Article

Enhancing Technology-Focused Entrepreneurship in Higher Education Institutions Ecosystem: Implementing Innovation Models in International Projects

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Abstract: Innovation models are key to fostering technology-focused entrepreneurship in higher education institutions (HEIs). These models create dynamic environments that encourage collaboration, creativity, and problem-solving skills among students and faculty. HEIs face several challenges in fostering entrepreneurship, including allocating sufficient financial and human resources, integrating entrepreneurship education across disciplines, and managing intellectual property. Overcoming these challenges requires HEIs to cultivate an entrepreneurial culture and establish strong partnerships with industry stakeholders. To achieve these goals, HEIs must adopt successful innovation models proven to work. This article presents an international case study highlighting such models and the factors contributing to their success. This study explores the implementation and impact of innovation models, specifically IDEATION and DEETECHTIVE, within HEIs to foster technology-focused entrepreneurship. By implementing numerous actions focusing on online education integration and the Quintuple Helix Innovation Model, these models support shifting engineering students' mindsets toward entrepreneurship. This research highlights the importance of academia–industry collaboration, international partnerships, and the integration of entrepreneurship education in technology-focused disciplines. This study presents two models. The first, IDEATION, focuses on open innovation and sharing economy aspects. This model underwent rigorous testing and refinement, evolving into the second model, DEETECHTIVE, which is more comprehensive and deep tech-focused. These models have been validated as effective frameworks for fostering entrepreneurship and innovation within HEIs. This study's findings underscore the potential of these models to enhance innovation capacity, foster an entrepreneurial culture, and create ecosystems rich in creativity and advancement. Practical implications include the establishment of open innovation-oriented structures and mechanisms, the development of specialized curriculum components, and the creation of enhanced collaboration platforms.

Keywords: entrepreneurship education; innovation training; academia-industry collaboration; technology entrepreneurship; incubators; international partnerships; problem-solving skills

1. Introduction

Innovation models are essential for fostering technology-focused entrepreneurship in universities. These models create dynamic environments that enhance student and faculty collaboration, creativity, and problem-solving skills. Integrating industry partnerships, incubators, and accelerators into university ecosystems provides essential resources, mentorship, and networking opportunities. These elements are crucial for transforming innovative concepts into successful enterprises. However, higher education institutions (HEIs) face multiple challenges in nurturing entrepreneurship. These challenges include allocating sufficient resources, integrating entrepreneurial education across various disciplines, effectively managing intellectual property, and developing a sustainable entrepreneurial culture. To address these issues, universities must adopt and develop new, effective models for supporting innovation. This involves strategic planning, engaging stakeholders, developing policies, and continuously evaluating and adapting entrepreneurship programs and initiatives.

The literature review supporting this study is divided into four main sections, as follows: Entrepreneurship Development at Higher Education Institutions, Open Innovation Paradigm in Education, Sharing Economy for HEIs, and the Role of the Quintuple Helix Innovation Model. Each section uniquely contributes to this study by providing theoretical frameworks, contemporary practices, and practical solutions that collectively enhance the understanding and implementation of technology-focused entrepreneurship within HEIs. These themes ensure a comprehensive review of the relevant literature, supporting the development of effective innovation models tailored for higher education institutions. The specific reasons for selecting the aforementioned topics are explained below. The role of entrepreneurship development in higher education is crucial for identifying gaps and opportunities in entrepreneurship education within HEIs, directly supporting this study's focus. Understanding entrepreneurship development helps illustrate how HEIs can contribute to economic growth and social development. Moreover, analyzing how entrepreneurial principles are integrated into various curricula, especially in engineering and science, aids in designing effective educational strategies. Open Innovation paradigms encourage collaboration and shared value creation, making them essential for fostering innovation in educational settings. Supported by the European Commission, these paradigms align with this study's goals of integrating external sources into internal innovation processes. The sharing economy model complements the Open Innovation paradigm. It helps HEIs optimize resources and reduce costs, addressing financial and human resource limitations. This model supports the development of collaborative networks, enhancing access to shared knowledge and infrastructure, as well as promoting sustainable practices within HEIs. Finally, the quintuple helix innovation model (QHIM) provides a holistic approach by integrating political, educational, economic, environmental, and social systems. This model emphasizes sustainable entrepreneurship, aligning with global trends toward eco-friendly and socially responsible business practices. The QHIM facilitates stronger connections between different sectors, enhancing the impact and reach of innovation initiatives within HEIs.

1.1. Background

1.1.1. Entrepreneurship Development at Higher Education Institutions

Innovation and entrepreneurship are pillars of social progress and national competitiveness in the global economy. Education serves as the primary arena for nurturing innovative and entrepreneurial talents. Higher education institutions (HEIs) promote innovation and entrepreneurship, significantly contributing to economic growth and social development [1,2]. Entrepreneurial education is essential for cultivating creativity and innovation. Studies show that institutional support mechanisms, such as business plan assistance and consultations with industry experts, are vital in influencing students' entrepreneurial activities and self-efficacy, shaping their entrepreneurial intentions [3,4]. Exposure to successful entrepreneurial models that attract students to business courses, and the approaches that offer tailored courses to non-business students, positively impact students' attitudes toward entrepreneurship, with a focus on social rather than financial benefits [5,6]. Over the past decades, there has been a notable gap in integrating entrepreneurship principles into engineering and science curricula; however, a significant improvement has recently been noticed [7,8]. Efficiently including entrepreneurship in engineering courses requires collaborative efforts across business and engineering schools and a multi-school approach to fully embed a robust entrepreneurial culture within HEIs. HEIs have been instrumental in shaping entrepreneurial mindsets among students, preparing them to succeed as entrepreneurs and managers. By integrating entrepreneurial principles into their curricula, HEIs equip students with the skills and knowledge to drive innovation and contribute to job creation and economic prosperity [9–11].

1.1.2. Open Innovation Paradigm in Education

Open Innovation (OI) and Open Innovation 2.0 (OI2) are increasingly popular paradigms that enhance the innovative capacities of institutions. OI leverages external sources to accelerate internal innovation and expand market opportunities [12]. A systematic literature review of over 50 articles revealed that open innovation and co-creation enable entrepreneurs to expand their knowledge and promote innovation despite challenges like resource scarcity and collaboration skills, highlighting the need for supportive programs and mechanisms [13]. OI2 further emphasizes collaboration, shared value creation, innovation ecosystems, exponential technologies, and rapid adoption. These paradigms enable universities to foster entrepreneurship, create viable business ventures, and equip students for success in the competitive global marketplace. Supported by the European Commission's Open Innovation Strategy and Policy Group (OISPG), these approaches are fundamental for higher education institutions aiming to lead global innovation and provide world-class experiences [14]. OI and OI2 facilitate innovation in education and support a shift toward more open and decentralized innovation models [15]. The growing importance of digital platforms as key venues for value creation aligns with these paradigms, offering new and experienced entrepreneurs opportunities to engage in expansive platform ecosystems [16]. Recent studies have focused on how OI and OI2 enhance collaboration networks between academia, business, and industry, fostering knowledge transfer, sustainability, and competitiveness [17]. These paradigms are central to Education 4.0, which promotes critical thinking skills through structured learning approaches like problem-based and project-based learning across various cognitive stages [18–21]. For technology-focused HEIs, OI and OI2 are essential in fostering a culture of innovation. They support new product development through "crowdsourcing and crowdfunding" [22,23] and enhance intergenerational collaboration among students and staff. Additionally, integrating business accelerators and incubators within HEIs strengthens these institutions by establishing extensive networks that bolster organizational sustainability and competitiveness [24–27].

1.1.3. Sharing Economy for HEIs

The sharing economy, a business model integral to Open Innovation, coordinates resource acquisition and distribution through online peer-to-peer activities, often for a fee. This model minimizes waste, boosts efficiency, and drives bottom-up change [28,29]. Its global value, projected to increase from USD 14 billion in 2014 to USD 335 billion by 2025 [30], highlights its potential to significantly reduce costs, optimize resources, and create new revenue streams [30–33]. Increasingly adopted by Higher Education Institutions (HEIs) worldwide, the sharing economy enhances resource efficiency, lowers costs, and improves consumer welfare. Integrating this model into HEIs' innovation strategies promotes collaborative networks, broadens access to shared knowledge, and supports sustainable consumption practices. By leveraging the sharing economy, HEIs can meet operational and educational goals while enhancing efficiency, sustainability, and equity [34–36].

1.1.4. Role of the Quintuple Helix Innovation Model

The quintuple helix innovation model (QHIM) offers a comprehensive framework for HEIs promoting sustainable entrepreneurship. It integrates five critical dimensions, as follows: political, educational, economic, environmental, and social. This integration facilitates synergies that enhance the connections between the economy, society, and democracy, crucial for addressing the socio-economic challenges of the twenty-first century and fostering socio-ecological transitions [37–40]. By adopting the QHIM, HEIs can nurture an entrepreneurial culture that supports green entrepreneurs and drives sustainable-smart innovations. This approach enhances connectivity among various stakeholders, leading to a more robust and impactful innovation ecosystem. Ultimately, implementing the QHIM provides holistic solutions that advance innovation development, significantly contributing to economic growth and job creation [41–43].

1.2. Aims, Objectives, and Goals

In recent years, HEIs have moved from traditional educational methods to online learning, emphasizing practicality, flexibility, and accessibility [21,44,45]. This shift allows universities to develop innovative educational formats, particularly those that foster international cooperation and bridge the entrepreneurship gap [21,46,47].

Proposed Innovative Model Objectives:

- Enhance entrepreneurship education for engineering and science students by developing a comprehensive curriculum that integrates entrepreneurship principles with their technical expertise;
- Leverage online learning to broaden access and enhance student collaboration within the HEI ecosystem and across international partnerships;
- Expand the theoretical framework to contribute to the body of knowledge on designing and implementing effective innovation models that foster entrepreneurship among engineering and science students [10].

Our primary goals are the following:

- Increase the number of engineering and science student entrepreneurs and foster a culture of innovation within HEIs;
- Facilitate knowledge exchange and joint ventures among students from partnering HEIs to strengthen international collaborations and promote a globally minded entrepreneurial mindset;
- Contribute to the development of a new generation of innovative and entrepreneurial engineers and scientists by realizing these aims, objectives, and goals.

Our research was led by four main questions:

- What strategies can be implemented to increase the number of engineering and science student entrepreneurs in HEIs?
- What are the key components of an effective innovation model for enhancing entrepreneurship within HEIs?
- How can international collaborations foster a globally-minded entrepreneurial mindset among students?

- What initiatives can be undertaken to develop a new generation of innovative and entrepreneurial engineers and scientists within HEIs?

The hypotheses below focus on integrating and utilizing different cutting-edge teaching and training approaches to develop students' innovation and co-creation skills. Each one of these hypotheses was evaluated as a part of the different actions of the two projects presented below (we assign each hypothesis to the corresponding project's actions according to the following pattern: project's acronym, action's number, and name). Thus, we built our work by considering the four following hypotheses:

- Implementing mentorship programs and providing access to entrepreneurship resources increase the number of engineering and science student entrepreneurs in HEIs (IDEATION: A.1 Digital access to infrastructure; IDEATION: A.5 Pre-incubation program GROW-up TECH; DEETECHTIVE: A.1 Talent Hunter Space; DEETECHTIVE: A.5 Pre-Incubation Mentoring Program GROW-up TECH; DEETECHTIVE: A.6 Start-up booster);
- Incorporating online education and open innovation topics into the curriculum significantly improves students' entrepreneurial skills and outcomes (IDEATION: A.3 Crowd Innovation; IDEATION: A.4 Testing crowdfunding opportunities; IDEATION: A.6 International Open Innovation Training IDEA-up; DEETECHTIVE: A.3 International Open Innovation Training: IDEA-up DEEP TECH; DEETECHTIVE: A.4 Deep Tech innovation challenges).
- HEIs that actively engage in international collaborations will report higher levels of entrepreneurial activity and innovation among their students (IDEATION: A.1 Digital access to infrastructure; IDEATION: A.2 Knowledge Triangle Networks; DEETECHTIVE: A.2 Deep Tech Dates; DEETECHTIVE: A.7 Knowledge hotspot).
- Integrating practical, real-world projects into the curriculum contributes to developing a new generation of innovative and entrepreneurial engineers and scientists (IDEATION: A.1 Digital access to infrastructure; IDEATION: A.3 Crowd Innovation; IDEATION: A.6 International Open Innovation Training IDEA-up; DEETECHTIVE: A.3 International Open Innovation Training: IDEA-up DEEP TECH; DEETECHTIVE: A.4 Deep Tech innovation challenges).

By addressing these research questions and testing these hypotheses, this study aims to provide a comprehensive framework for fostering a culture of innovation and entrepreneurship within HEIs, ultimately contributing to the development of a new generation of innovative engineers and scientists. The first hypothesis is built on the premise that mentorship and resources are critical for fostering entrepreneurship. By offering continuous mentorship programs and comprehensive access to resources, students can receive the guidance and support necessary to transform their ideas into entrepreneurial ventures. The IDEATION and DEETECHTIVE projects included actions specifically aimed at supporting this hypothesis by providing the needed infrastructure and mentorship to cultivate student entrepreneurs. The second hypothesis is based on the idea that integrating online education and open innovation into the curriculum can enhance students' entrepreneurial capabilities by exposing them to a wider range of resources and perspectives. This approach fosters a deeper understanding of entrepreneurship. The IDEATION and DEETECHTIVE projects included actions designed to integrate these topics into the learning environment, thereby improving entrepreneurial outcomes. The third hypothesis is developed from the concept that international collaborations provide unique opportunities for cross-cultural learning and networking, which are essential for fostering a global entrepreneurial mindset. Engaging in international partnerships allows students to learn from diverse perspectives and engage in collaborative problem-solving. The projects facilitated cross-institutional workshops and networking events, aiming to strengthen international collaborations and promote entrepreneurial activities. The fourth hypothesis posits that hands-on, practical projects help students apply their knowledge in real-world scenarios, fostering innovation and an entrepreneurial mindset. By incorporating real-world projects into the curriculum, HEIs can bridge the gap between theoretical knowledge and practical application. The

IDEATION and DEETECHTIVE projects included actions focused on integrating practical projects and international open innovation training, demonstrating the importance of this approach in developing innovative and entrepreneurial skills.

In the subsequent sections, the methods section introduces the innovation models developed and the international case studies that facilitated their evaluation. The results section highlights key findings from the projects used as evaluation frameworks. The discussion section assesses the strengths and weaknesses of the models, offering perspectives for future enhancements. Finally, the conclusions recommends that HEIs implement successful innovation models and cultivate an ecosystem that drives sector-wide innovation.

2. Methods

In the following section, we are focusing on the need to define an actionable innovation model for entrepreneurial learning before presenting the IDEATION model for HEI Entrepreneurship and then its improvement as the DEETECHTIVE.

The development of the IDEATION model involved four HEI participants (Wroclaw University of Science and Technology (WUST) from Poland, the Holon Institute of Technology (HIT) from Israel, the University of La Laguna (ULL) from Spain, and the Institute for Industrial Management (FIR) from Germany), over 800 students of different degrees, and over 400 staff members, all trained (and mentored) to innovation and entrepreneurship from said four HEIs (duration 18 months: from July 2022 to December 2023).

The DEETECHTIVE model improving the previous one involved five HEIs (WUST, HIT, EPF School of Engineering (EPF) from France, Centria University of Applied Sciences (CENT) from Finland, and the University of Genova (UNIGE) from Italy). DEETECHTIVE had more than 350 students and nearly 200 staff participants involved in innovation training and mentoring from all five HEIs (duration: 8 months, from May 2023 to December 2023).

The reason for creating consortia composed of four HEIs and one business support organization (BSO) in IDEATION and five HEIs and one BSO in DEETECHTIVE was a compromise between geographical span, limited budget, common goals, and participation in EIT KICs (knowledge and innovation communities). Some of these restrictions were set by the funding institution—for example, the consortium should include more non-KIC organizations than organizations that are KIC members.

2.1. Needs Definition for an Actionable Innovation Model for Entrepreneurial Learning

Online education integration is essential for connecting students and educators across different geographic locations, facilitating international collaboration and the exchange of ideas, which are critical for multi-site innovation. It allows for the scalable and consistent delivery of educational content, ensuring that innovative practices and entrepreneurial training can be uniformly implemented and accessed by participants worldwide, thus supporting a unified approach to innovation across multiple sites. Conclusions resulting from the literature review show that the quintuple helix innovation model is vital, as it incorporates diverse sectors (political, educational, economic, environmental, and social), promoting inclusive and sustainable innovation practices that are applicable and beneficial in an international context. By fostering collaboration among various stakeholders globally, the QHIM enhances synergy and connectivity between international and multi-site institutions, driving impactful and cohesive innovation efforts across different regions. Therefore, to enhance entrepreneurship within universities, an effective innovation model must incorporate two key components:

- Online Education Integration: Reflecting recent shifts in the educational landscape, the model should offer all training and activities online. The curriculum should focus broadly on entrepreneurship, explicitly addressing Open Innovation topics such as crowdsourcing, crowdfunding, and Social Product Development (SPD). These elements are crucial in academic settings to help students understand the benefits of engaging in innovation challenges and to recognize alternative funding methods for their projects;

- Alignment with the Quintuple Helix Innovation Model: The model should incorporate the QHIM framework, involving academia, industry, society, public authorities, and the natural environment. This integration supports adopting the sharing economy concept, addressing common issues technology-focused HEIs face, such as costly underutilized research infrastructure. The model can offer extensive benefits by implementing infrastructure sharing among faculties, departments, and external entities like startups, small- and medium-sized enterprises (SMEs), and other HEIs. Faculties are encouraged to develop pre-incubation programs tailored explicitly for engineering students.

These considerations have shaped the development of a general model concept, which serves as the foundation for the research discussed in this paper. This concept represents the initial step in our proposed research methodology, depicted in Figure 1, STEP 0.

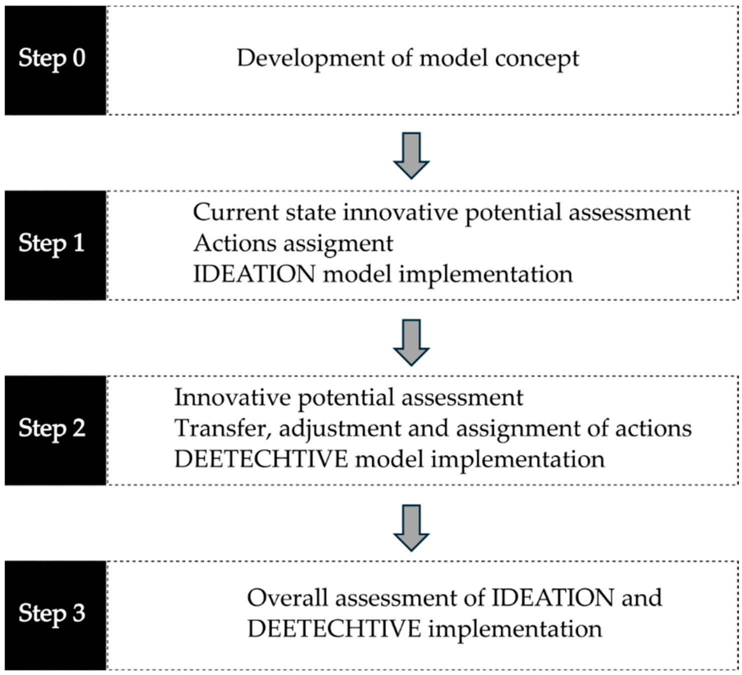

Figure 1. General scheme presenting research methodology.

Innovation Model Focus Areas:

- Sharing Economy: Promotes resource optimization and cost reduction;
- Open Innovation: Facilitates collaborative innovation across various sectors;
- Social Product Development: Encourages the creation of socially beneficial products and services.

This action-based model addresses significant shifts in work, innovation creation, and learning methods. It includes six specific actions that define the model's structure, each aligned with one of the three main paradigms. Figure 1 illustrates the complete research methodology and its structural outline.

The initial step in our research methodology involves assessing the innovative potential of Higher Education Institutions (HEIs), as depicted in Figure 1. This assessment is carried out using HEInnovate [48], a self-reflection tool designed specifically for HEIs. HEInnovate allows institutions to analyze their performance across eight key areas:

- Leadership and Governance: Evaluating the leadership strategies and governance structures in place;
- Organizational Capacity: Assessing the adequacy of funding, human resources, and incentive mechanisms;

- Entrepreneurial Teaching and Learning: Review the approaches and methodologies used to teach entrepreneurship;
- Preparing and Supporting Entrepreneurs: Examining the support systems available for budding entrepreneurs;
- Digital Transformation and Capability: Analyzing the institution's digital technologies and their integration into teaching and administrative processes;
- Knowledge Exchange and Collaboration: Looking at how effectively the institution engages with external entities and shares knowledge;
- The Internationalized Institution: Measuring the global engagement and impact of the institution.

Each HEI participating in an innovation project based on the models discussed is expected to perform this analysis individually to evaluate its current state and identify areas for improvement.

2.2. The IDEATION Model: 6 Actions for HEI Entrepreneurship

The IDEATION innovation model is designed to enhance entrepreneurial and innovation capacities within Higher Education Institutions (HEIs) and significantly impact their surrounding ecosystems. It incorporates six targeted actions to boost innovativeness and entrepreneurial skills intended for deployment within international partnerships (Figure 2).

Main Objectives of the IDEATION Model:

- Digital Resource Accessibility: Open digital resources to increase awareness and provide access to competencies, experiences, and infrastructure through a newly developed format of digital services;
- Strengthening Knowledge Partnerships: Enhance partnerships within the knowledge triangle by creating spaces for collaborative networks and fostering opportunities for new cooperation;
- Open Innovation Practices: Test and popularize Open Innovation-based approaches to directly accelerate the innovation process within HEIs and their broader ecosystems;
- Quality Enhancement in Innovation and Entrepreneurship Education: Establish a pre-incubation program and international open innovation training to improve the quality of innovation and support entrepreneurial education.

As detailed in Figure 2, the IDEATION model is built around these six actions to drive the entrepreneurial and innovative capabilities of HEIs.

2.2.1. Digital Access to Infrastructure

This action is designed to enhance the innovativeness and entrepreneurial capacity of HEIs and provide startups, SMEs, and research teams with direct access to advanced, high-tech research infrastructure under preferential terms. To facilitate this, each partner will create and maintain a digital database of available infrastructure on a dedicated digital platform. This initiative is rooted in the sharing economy model, aiming to optimize the use of existing resources.

The approach specifically addresses a prevalent issue in larger HEIs; there is often a lack of awareness about the range of equipment available across different labs. This unawareness can lead to unnecessary duplication of infrastructure and underutilization.

By making information about available resources easily accessible, the action aims to improve infrastructure utilization rates and foster a more collaborative environment within the HEI ecosystem.

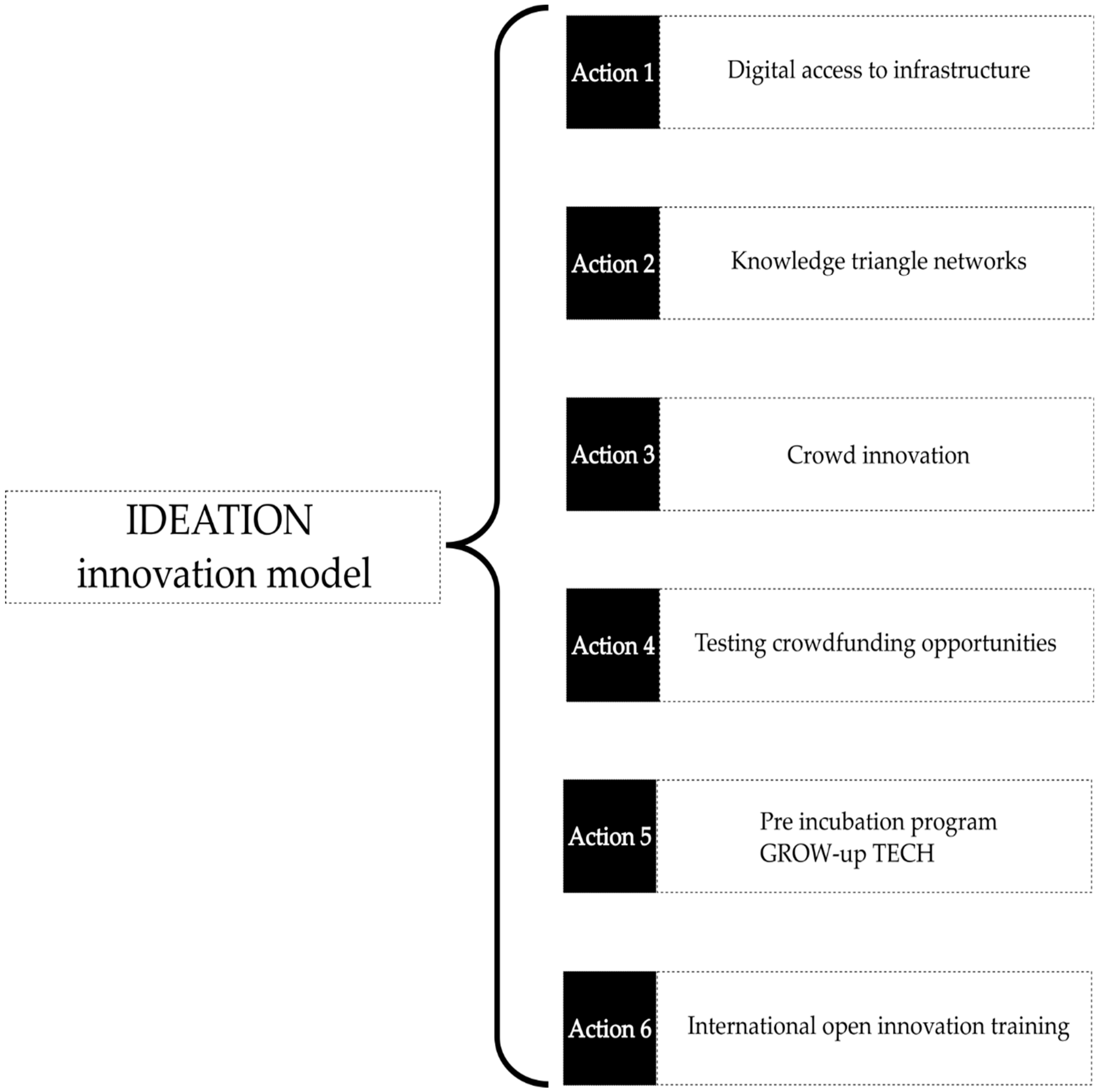

Figure 2. Actions included in the IDEATION innovation model.

2.2.2. Knowledge Triangle Networks

This action focuses on enhancing partnerships within the knowledge triangle by creating collaborative spaces and fostering new cooperations. It aims to integrate and engage more deeply with the innovation ecosystems of various partners through two main strategies:

- Data-Driven Cluster Formation: This approach utilizes data mining techniques to analyze real experiences. It identifies similarities among participants to form potential clusters. This method simplifies and accelerates the development of new partnerships and networks, making the process more efficient and targeted;
- Organization of Innovative Events: These events are designed to assemble representatives from different segments of the knowledge triangle. These gatherings facilitate the initiation of new collaborations by providing a platform for sharing experiences, challenges, and ideas. The events aim to foster a rich knowledge exchange and drive collective innovation efforts.

2.2.3. Crowd Innovation

This action is designed to test and promote Open Innovation 2.0-based approaches, specifically emphasizing crowdsourcing to accelerate the innovation process within Higher Education Institutions and their ecosystems. The primary goal is to create an environment conducive to innovation-driven research, ultimately enhancing the innovation capacity of HEIs, as follows:

- Implementation of Digital Platforms: A dedicated digital platform will be utilized to collate various crowdsourcing-based challenges. This platform will serve as a hub for generating a wide array of innovative solutions by tapping into the collective intelligence of a global network;
- International Collaboration: The initiative will be conducted internationally, involving participants from all partner countries. This global approach diversifies the range of innovative ideas, fosters cross-border collaborations, and enriches the research environment through international insights.

This action leverages digital tools and international cooperation to cultivate a dynamic and responsive innovation ecosystem within and across HEIs.

2.2.4. Testing Crowdfunding Opportunities

Crowdfunding, a key component of Open Innovation 2.0, will be actively promoted by initiating competitions for crowdfunding campaigns and organizing related workshops. These initiatives are designed to:

- Foster Innovative Crowdfunding Initiatives: These competitions and workshops aim to generate a diverse array of innovative crowdfunding projects by engaging students and researchers in practical activities;
- Develop Entrepreneurial Skills: This approach cultivates an entrepreneurial mindset among participants, providing them with hands-on experience in alternative financing mechanisms crucial for funding research and innovative ideas;
- Enhance Access to Funding: Through real-world application, participants will gain direct access to funding sources while simultaneously receiving immediate market feedback on their proposed solutions. This dual benefit accelerates the funding process and integrates valuable market insights into the development phase.

This structured approach to crowdfunding underpins the broader objectives of fostering a culture of innovation and practical financial acumen within the HEI ecosystem.

2.2.5. Pre-Incubation Program "GROW-Up TECH"

The GROW-up TECH pre-incubation program was established to foster innovation and strengthen entrepreneurial education. This program supports numerous startups through a comprehensive approach:

- Structured Support: Startups benefit from extensive training sessions, workshops, and expert supervision. EPIC [49] and KTH [50] assessments further enhance this structured environment, which provides critical evaluations and feedback to refine business strategies and technological developments;
- Mentoring for Students: Students participating in the program receive mentoring to develop their abilities to design innovative products or services. This hands-on guidance is crucial for nurturing practical skills and entrepreneurial thinking, empowering students to translate academic knowledge into market-ready innovations.

This action accelerates the development of new enterprises and embeds a strong entrepreneurial culture within the academic environment.

2.2.6. International Open Innovation Training IDEA-Up

We developed and implemented an International Open Innovation Training program to bolster entrepreneurial education and innovation quality. This program will focus on core concepts such as entrepreneurship, Open Innovation 1.0 and 2.0, and Social Product

Development. It will utilize online platforms to deliver state-of-the-art approaches, methods, and case studies, emphasizing Open Science and SPD. The training material will be compiled into a digital handbook with all related resources and instructional content. The assessment of the innovative potential of our partners is a critical first step in the action selection and assignment process.

According to our research methodology, the second step involves adapting and refining the most effective actions based on this assessment. This process led to the formation of a new consortium built on the foundations of initial evaluations. Each new partner will assess innovative potential, informing the assignment of specific actions in the revised model. This systematic approach ensures that our collaborative efforts are tailored to maximize the strengths and opportunities within the consortium.

2.3. The DEETECHTIVE Model: An Enhanced IDEATION Model

The DEETECHTIVE model builds upon the revised IDEATION framework, specifically focusing on Deep Tech and integrating previously mentioned enhancements.

Model Overview and Integration: Figure 3 illustrates the interactions between the IDEATION and DEETECHTIVE models concerning key paradigms such as the Sharing Economy, Open Innovation, entrepreneurship, Deep Tech, and Social Product Development. It details how specific actions from the IDEATION model (I1–I6) are adapted and transferred to the DEETECHTIVE model (I2 → D2, I3 → D4, I5 → D5, I6 → D3), ensuring continuity and evolution of the initial intents.

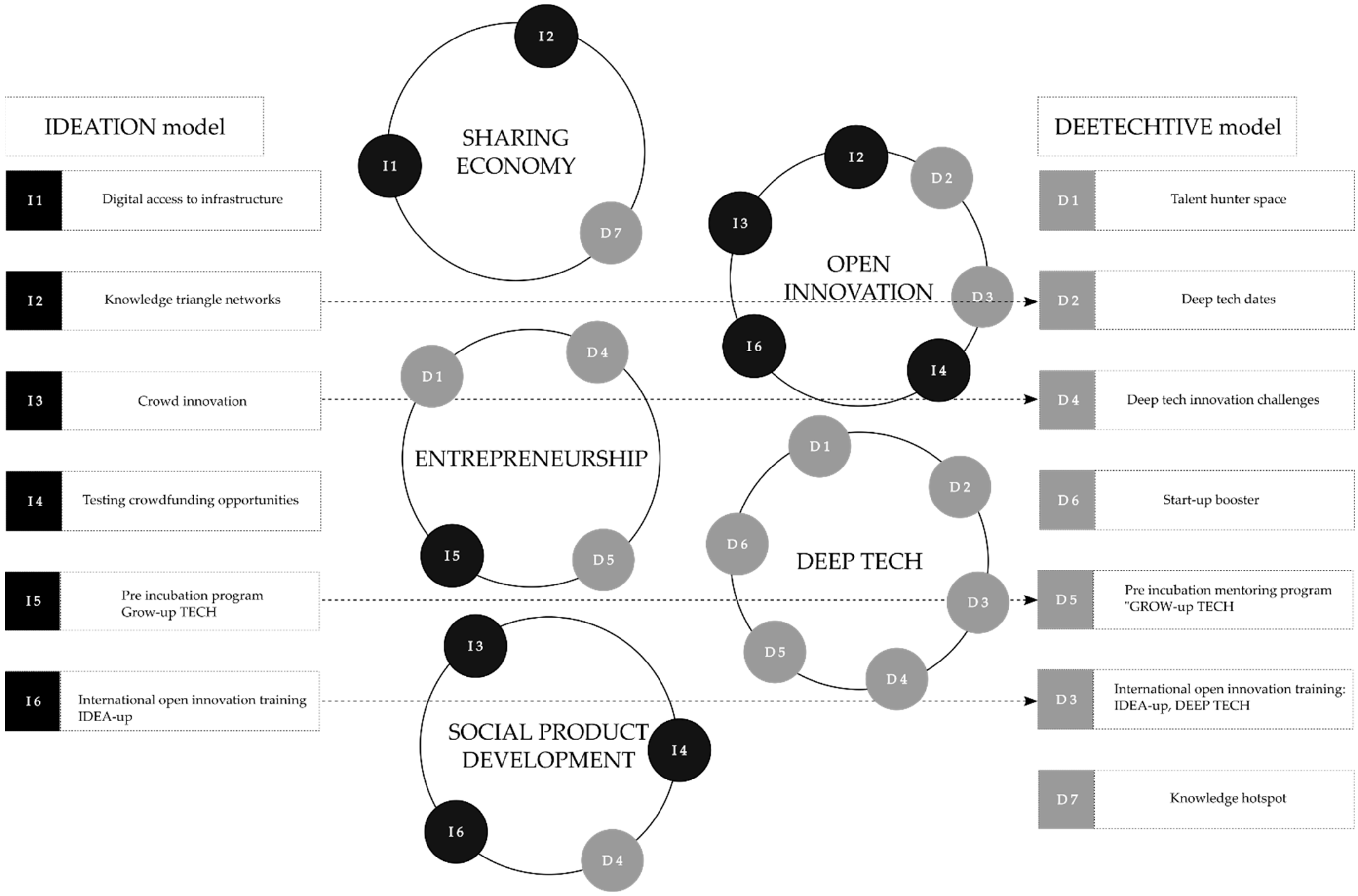

Figure 3. General scheme presenting innovation models enhancing entrepreneurship in HEI ecosystems.

Alignment with the Quintuple Helix Innovation Model: Both the IDEATION and DEETECHTIVE models align with the quintuple helix innovation model, which integrates universities, industry, government, society, and the environment, adhering to advanced innovation frameworks. However, the DEETECHTIVE model shifts its focus slightly, emphasizing three main pillars:

Deep Tech: Enhancing capabilities in cutting-edge technologies.

Open Innovation and Open Science: Encouraging more transparent and collaborative innovation processes.

Social Product Development: Focusing on creating socially beneficial products.

Primary Objectives of the DEETECHTIVE Model: Developing the Talent Hunter Space: This pan-European platform aims to identify and cultivate deep tech talent within the student community, facilitating the growth of skilled innovators.

Figure 3 illustrates the interactions between the IDEATION and DEETECHTIVE models mentioned earlier.

Accelerating Innovation: It tests and promotes Open Innovation 2.0 methodologies, supporting deep tech startups within HEIs and their wider ecosystems. This initiative aims to speed up the innovation cycle and rapidly bring cutting-edge solutions to the market.

- Enhancing Educational Quality: The model enhances the quality of innovation and supports entrepreneurial education through initiatives like the International Open Innovation Training: IDEA-up DEEP TECH and the pre-incubation mentoring program: GROW UP TECH. These programs are designed to equip participants with the necessary skills and knowledge to succeed in high-tech entrepreneurial endeavors.
- Disseminating Knowledge: By collecting and sharing success stories and lessons learned, the model helps disseminate valuable insights across local and international ecosystems, enhancing cooperation and knowledge exchange.
- Vision and Focus of the DEETECHTIVE Model: The DEETECHTIVE model envisions a transformational path toward future advancements by enhancing the capacity for entrepreneurship and innovation through open innovation and open science. It specifically targets building innovative capacities in fields such as Advanced Manufacturing, aerospace, automotive, remote sensing, artificial intelligence, machine learning, big data, semantic web, robotics, and emerging Web 3.0 technologies, including the internet of things, blockchain, distributed ledgers, and non-fungible tokens (NFTs). The detailed actions encompassed by the DEETECHTIVE innovation model are outlined in Figure 4.

The DEETECHTIVE innovation model enhancing entrepreneurship in HEI ecosystems is based on 7 actions.

2.3.1. Talent Hunter Space

The DEETECHTIVE model's first action, Talent Hunter Space (THS), is designed as a pan-European talent and skills development platform. This platform aims to support participating HEIs in swiftly identifying, skilling, reskilling, and upskilling deep tech talents within the DEETECHTIVE student community. By facilitating international talent hunting, THS enhances the innovative capacity and entrepreneurial prowess of HEIs, precisely addressing the ecosystems' demands for student training in deep tech areas.

Implementation Details:

- Digital Database Creation: Each project partner will develop a digital database dedicated to deep tech, innovation, and entrepreneurship. This resource will boost awareness among partners and improve access to existing and new solutions alongside support programs at each HEI;
- Training for Implementation: Academic and non-academic staff will receive targeted training sessions to implement the THS effectively. These sessions will focus on enhancing competencies in career counseling and skills profiling for students, ensuring that the platform identifies and nurtures talent effectively.

This strategic initiative tackles a prevalent challenge in large HEIs by streamlining talent discovery and development, ensuring that students equipped with high-demand tech skills are prepared to meet the needs of modern industries.

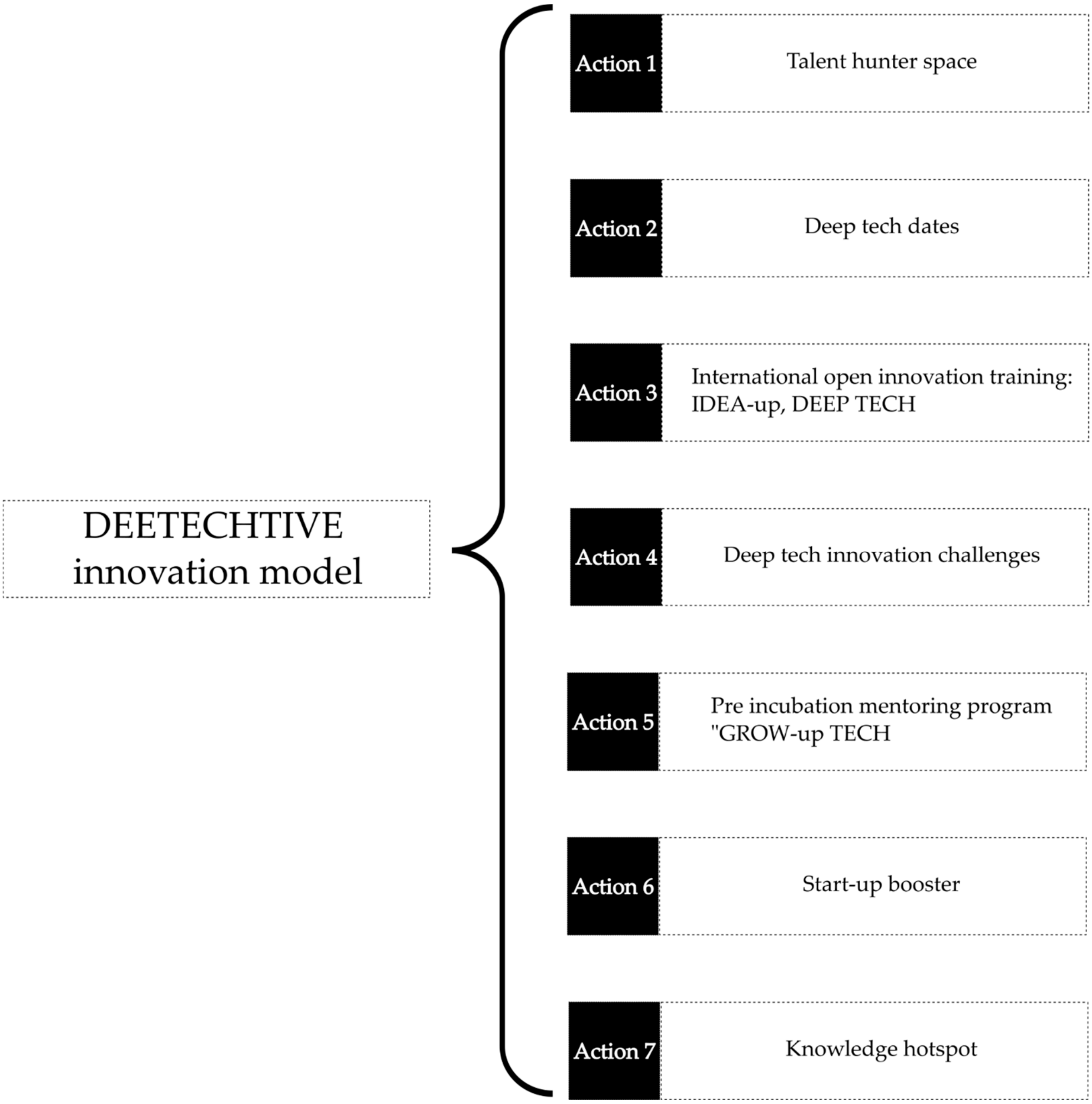

Figure 4. Actions included in the DEETECHTIVE innovation model.

2.3.2. Deep Tech Dates

Action 2 aims to fortify partnerships within the knowledge triangle through the innovative concept of "Deep Tech Dates". This new format is designed to build and enhance collaborative networks, facilitating stronger integration and engagement with partners' innovation ecosystems. The implementation of deep tech dates is as follows:

- Event Organization: Deep Tech Dates are a series of targeted events that convene representatives from various segments of the knowledge triangle—academia, industry, and government;
- Purpose and Activities: These gatherings are structured to allow participants to share experiences, discuss current challenges, exchange ideas, and forge new collaborations. The focus is creating a dynamic forum for open dialogue and partnership development that directly supports deep tech initiatives.

Goals of Action 2:

- Enhanced Collaboration: By introducing a structured yet flexible environment for interaction, deep tech dates aim to break down traditional barriers between different sectors and foster a seamless exchange of knowledge and resources;
- Innovation Ecosystem Integration: This action facilitates deeper engagement with existing innovation ecosystems and helps identify and leverage synergistic opportunities for all involved parties.

This approach ensures that all participants are better positioned to contribute to and benefit from shared innovation endeavors, ultimately leading to more robust and productive partnerships.

2.3.3. International Open Innovation Training: IDEA-Up DEEP TECH

Action 3 aims to elevate innovation quality and bolster entrepreneurial education through the development of the International Open Innovation Training: IDEA-up DEEP TECH. This initiative focuses on key areas such as Deep Tech, Open Innovation, and social product development.

Program Details:

- Comprehensive Curriculum: A 50 h lecture-based program will be implemented, designed to address the cutting-edge aspects of Deep Tech, Open Innovation, and social product development. The curriculum aims to design and promote high-tech solutions, enhancing participants' innovative capabilities;
- Educational Approach: The program will foster an entrepreneurial mindset among students by providing practical knowledge through an immersive learning experience. Students will be organized into international cross-disciplinary teams and engage in problem-based learning (PBL). This approach is intended to deepen their understanding and application of complex concepts by solving real-world problems [19,20,51].

Goals of Action 3:

- Strengthen Entrepreneurial Education: The program strengthens the entrepreneurial offerings at HEIs by integrating advanced technological and innovative teachings;
- Enhance Student Innovation Capacity: Through collaborative and problem-oriented education, students are equipped with the necessary skills to navigate and succeed in the competitive fields of technology and innovation.

This action ensures that HEIs enhance their educational impact by providing a robust framework for students to develop essential skills in innovation and entrepreneurship.

2.3.4. Deep Tech Innovation Challenges

This action is designed to expedite the innovation process within HEIs and their broader ecosystems by implementing and promoting Open Innovation 2.0-based strategies, specifically targeting support for deep tech (DT) startups. The goal is to create an environment that fosters innovation-driven research and enhances the overall innovation capacity of HEIs.

Implementation Strategies:

- Structural Development: This action involves setting up infrastructures and conditions optimal for innovation-driven research. This structure aims to support DT startups by providing the necessary tools and resources to thrive in a competitive ecosystem;
- Crowdsourcing Initiatives: A pivotal component of this action is using crowdsourcing to tackle DT-focused challenges. A digital platform will collect these challenges and facilitate the submission of innovative solutions from a global community;

- International Collaboration: This initiative will be rolled out internationally, involving participants from all consortium countries, to ensure a diverse range of insights and solutions, thereby enriching the innovation process.

This approach accelerates innovation within HEIs and cultivates a robust network of international collaborations, enhancing the global impact of the consortium's efforts.

2.3.5. Pre-Incubation Mentoring Program: GROW-Up TECH

Action 5 is designed to enhance and complement the initiatives outlined in Action 3 by establishing the pre-incubation mentoring program: GROW-up TECH. This program specifically targets mentoring students in creating and developing Deep Tech-focused businesses.

Program Details:

- Workshop Series: A series of targeted workshops will be organized to provide foundational support and guidance to students. These workshops are structured to help participants refine their business ideas and develop viable business models tailored to the unique demands of Deep Tech industries;
- International Collaboration: The program incorporates an international dimension to broaden the scope of learning and innovation. Students will be grouped into international teams, fostering cross-cultural collaboration and enabling them to leverage diverse perspectives and expertise in developing their business ideas.

This action not only supports students in navigating the complexities of Deep Tech entrepreneurship but also encourages a collaborative spirit across borders, enhancing the global reach and impact of their innovative ventures.

2.3.6. Start-Up Booster

The start-up booster action is designed to streamline and enhance the support infrastructure for Deep Tech (DT) start-ups within participating HEIs. This initiative focuses on consolidating and cataloging entrepreneurs' services and support mechanisms, including mentoring, legal advice, and intellectual property protection.

Implementation and Analysis:

- Service Cataloging: All participating HEIs will initially catalog the available support services to ensure startups have easy access to the necessary resources;
- Cross-Consortium Analysis: A thorough analysis across the consortium will be performed to align the specific needs of startups and scale-ups with the available HEI support. This ensures that the resources provided are precisely tailored to meet the demands of the startups;
- Targeted Support Program: The DEETECHTIVE initiative will offer two months of flexible and targeted support following the analysis. This support package includes specialized training sessions, supervisor assistance, and evaluations using EPIC and KTH assessment tools.

Direct Startup Support (outcome): As a result of these concerted efforts, several startups will receive direct, customized support that addresses their specific operational, technical, and developmental needs.

2.3.7. Knowledge Hotspot

The primary goal of Action 7 is to compile and share success stories and lessons learned from the activities implemented under the IDEATION and DEETECHTIVE models. This action is vital for enhancing knowledge and fostering continuous improvement within partner HEIs and their broader ecosystems.

Implementation and Impact:

- Knowledge Sharing: This initiative aims to distribute valuable information across partners' local ecosystems and cooperation networks by gathering insights from all implemented actions. This dissemination helps replicate successful strategies and avoid past pitfalls, strengthening future endeavors;

- STEP 3—Comprehensive Evaluation: As the final step in our research methodology, STEP 3 thoroughly evaluates the overall implementation of the IDEATION and DEETECHTIVE models. This evaluation is conducted using dedicated Key Performance Indicators (KPIs), which are essential for measuring the effectiveness of each action and ensuring that the implementation is aligned with the intended outcomes;
- Transparent Monitoring and Evaluation (outcome): KPIs facilitate transparent and objective monitoring of the models' implementation, providing a clear benchmark for assessing progress and identifying areas for further enhancement.

2.4. IDEATION and DEETECHTIVE Models Effectiveness

The models' effectiveness was measured by considering the ratio (noted as the completion rate) between the expected number and the achieved number of predefined key performance indicators (KPIs), namely:

- Start-ups/scale-ups supported;
- Students trained with a view to innovation and entrepreneurship;
- Students mentored;
- Academic staff members trained with a view to innovation and entrepreneurship;
- Academic staff members mentored;
- Non-academic staff (e.g., professional staff, support staff) trained with a view to innovation and entrepreneurship;
- Non-academic staff mentored;
- Improved support structures and mechanisms (including successful infrastructure sharing, innovation challenges created, and crowdfunding campaigns submitted);
- New partnerships established;
- Start-ups created.

The KPIs were assigned to each action separately. The detailed breakdown of the planned KPIs per action can be found in Appendix A. Key performance indicators (KPIs) are segmented by actions.

3. Results

3.1. Innovative Potential Assessment

The research methodology outlined in Figure 1 was initiated by four HEIs: the Wroclaw University of Science and Technology (WUST), the Holon Institute of Technology (HIT), the University of La Laguna (ULL), and the Institute for Industrial Management (FIR). As part of the initial phase, these institutions utilized the HEInnovate self-reflection tool to assess their innovative potential. This assessment is essential for universities to strategically allocate resources and make informed decisions that enhance their competitiveness and innovation capabilities in a rapidly changing environment (Figure 1). By understanding their strengths and weaknesses in innovation, these institutions can prioritize initiatives, foster collaborations, and adapt to new trends, ensuring they remain adaptable and effective in meeting evolving societal challenges (Table 1).

Evaluating "Leadership and Governance" across institutions revealed that the Holon Institute of Technology (HIT) demonstrated strong leadership qualities characterized by effective strategic direction and decision-making capabilities. In contrast, Wroclaw University of Science and Technology (WUST) and the University of La Laguna (ULL) showed potential for enhancing their leadership initiatives to guide their strategic goals better. In "Organizational Capacity", HIT showcased a robust framework attributed to efficient resource allocation and well-structured incentive mechanisms. Conversely, WUST and ULL were identified as needing enhanced resources and incentives to bolster their organizational strength and support their institutional objectives. Regarding "Entrepreneurial Teaching and Learning", ULL excelled in creating an environment conducive to student innovation and creativity. Meanwhile, both WUST and the Institute for Industrial Management (FIR) were recognized as having opportunities to improve their entrepreneurial education approaches to foster entrepreneurial spirit among students. For "Preparing and Supporting Entrepreneurs", HIT stood out with its comprehensive support programs and networks, serving as a potential model for WUST and FIR to emulate to enhance their systems for nurturing entrepreneurial ventures.

Table 1. IDEATION—Initial assessments.

Key Areas	WUST	HIT	ULL	FIR	Avg.
Leadership and Governance	2.0	4.6	2.0	3.0	2.9
Organizational Capacity: Funding, People, and Incentives	1.0	4.0	1.6	3.6	2.6
Entrepreneurial Teaching and Learning	2.0	2.8	1.8	3.0	2.4
Preparing and Supporting Entrepreneurs	2.0	3.0	1.8	1.8	2.2
Digital Transformation and Capability	2.4	2.8	3.8	3.0	3.0
Knowledge Exchange and Collaboration	1.6	2.0	2.8	4.0	2.6
The Internationalized Institution	1.6	3.2	2.0	1.8	2.2
Measuring Impact	1.5	1.3	1.2	1.6	1.4

In "Digital Transformation and Capability", ULL is proficient in leveraging technology to drive innovation. This suggests that WUST and FIR could benefit from strengthening their digital capabilities to keep pace with rapid technological advancements.

3.2. Actions Assignment and IDEATION Model Implementation

Following the innovative potential assessment results, a comprehensive plan for assigning specific actions within the IDEATION model was formulated. This strategic approach enabled the transformation of the model into a significant project under the European Institute of Innovation and Technology (EIT) Higher Education Institutions Initiative, titled "Innovation Capacity Building for Higher Education" [52]. Coordinated by EIT Raw Materials [53], this initiative bolsters innovation and entrepreneurship within academia. The project, named IDEATION: Innovation and Entrepreneurship Actions and Training for Higher Education, successfully secured funding of EUR 1.2 million from the knowledge and innovation communities (KICs) of EIT Manufacturing [54]. Officially launched in July 2022, the IDEATION project was scheduled to run until June 2024. It included a consortium of five partners from five different countries: the Wroclaw University of Science and Technology (WUST) in Poland as the lead partner, the Holon Institute of Technology (HIT) in Israel, the University of La Laguna (ULL) in Spain, the Institute for Industrial Management (FIR) in Germany, and CRIT Srl in Italy. This project was built upon the six key actions identified earlier. The innovative potential assessment, as detailed in Table 2, was instrumental in determining each partner's role and level of involvement in these actions, ensuring a tailored approach that leverages each institution's unique strengths and capabilities. Table 2 details the specific actions each partner was involved in and the extent of their participation.

The project activities were clearly defined and quantified, and they were structured into three phases, as follows: Phase 1, from July to December 2022; Phase 2A, from January to December 2023; and Phase 2B, from January to June 2024. The structure of the actions—their number and length—results from the call requirements. Table 3 details the specific breakdown of the key performance indicators (KPIs).

Table 2. Participation in the IDEATION actions.

Participation in Particular Actions		WUST	HIT	ULL	FIR	CRIT
A.1	Digital access to infrastructure	✔	✔	✔	✔	✔
A.2	Knowledge Triangle Networks	✔	✔	✔	✔	✔
A.3	Crowd Innovation	✔	✔	✔	✔	✔
A.4	Testing crowdfunding opportunities	✔		✔	✔	
A.5	Pre-Incubation Program GROW-up TECH	✔		✔		✔
A.6	International Open Innovation Training IDEA-up	✔	✔	✔	✔	

Table 3. IDEATION—Planned KPIs.

IDEATION KPIs	Phase 1	Phase 2A	Phase 2B	Overall
Start-ups/scale-ups supported	3	3	3	9
Students trained with a view to innovation and entrepreneurship	260	375	165	800
Students mentored	22	30	14	66
Academic staff members trained with a view to innovation and entrepreneurship	60	75	35	170
Academic staff members mentored	8	8	0	16
Non-academic staff (e.g., professional staff, support staff) trained with a view to innovation and entrepreneurship	60	75	35	170
Non-academic staff mentored	8	8	0	16
Improved support structures and mechanism	19	33	10	62
New partnerships established	1	1	1	3
Start-ups created	0	0	4	4

Moreover, the IDEATION project has achieved significant results.

3.2.1. Research Infrastructure Sharing

During this project, the partners developed a model that allows remote access to technologically advanced laboratories worldwide, including robotic control. This model, supported by the SYNERGY meta-platform [55,56], facilitates digital resource sharing, raises awareness, and enhances access to competencies and infrastructure. It has been implemented and tested, enabling sharing between enterprises and universities.

3.2.2. Tech Dates Events

To create a community of interest, the IDEATION team established a new format of open seminars to strengthen partnerships within the knowledge triangle and foster new cooperative networks. These events, supported by the SYNERGY meta-platform, promote interaction and collaboration.

3.2.3. Innovation Support Model Validation

An innovation support model based on open innovation and the sharing economy was validated. This included developing a series of innovation challenges that utilized crowdsourcing and crowdfunding, primarily focusing on developing new technologically advanced products to accelerate innovation processes across enterprises, universities, and surrounding ecosystems.

3.2.4. IDEA-Up Platform and Training Model

The development of the IDEA-up platform [57] and an open online training model, International Open Innovation Training IDEA-up, which focused on entrepreneurship, innovation (especially Open Innovation), and Social Product Development in advanced manufacturing technologies, were crucial contributions of the project to the HEI community. The training consists of three main modules:

- Module 1: Innovation and Entrepreneurship (12 lectures);
- Module 2: Open Innovation (7 lectures);
- Module 3: Social Product Development (4 lectures).

3.2.5. From the IDEA-Up Platform to Deep Tech

The IDEA-up platform provided insights into deep tech and leading-edge approaches, helped to develop innovation and entrepreneurial skills, inspired startup creation, and offered access to lectures from international researchers. Participants also received a free certification.

3.2.6. The "GROW-Up TECH" Pre-Incubation Program

The training was enriched by the "GROW-up TECH" pre-incubation program model, which fosters innovation by supporting the establishment of startups in technologically advanced fields. GROW-up TECH and IDEA-up embody knowledge sharing, enhance innovation quality, and support entrepreneurial education. They also offer an alternative development path to a corporate career, creating conducive conditions for generating advanced innovations.

3.3. Enhancing the IDEATION Model with Knowledge Transfer and Continuous Adjustments: The DEETECHTIVE Model

During the successful implementation of the IDEATION project, the EIT's HEI Initiative: Innovation Capacity Building for Higher Education, released another call for proposals. Two IDEATION project partners, respectively, WUST and HIT, decided to continue their collaboration and apply for a new project. They aimed to validate further and develop the IDEATION innovation model and formed a new network of partners. Another assessment of innovative potential was conducted, showing an increase in innovativeness at both WUST and HIT. Three additional HEIs were invited to join the new consortium: the EPF School of Engineering (EPF) from France, Centria University of Applied Sciences (CENT) from Finland, and the University of Genova (UNIGE) from Italy.

This allowed for upgrading the IDEATION model to the new DEETECHTIVE one, which is built on the IDEATION model with several enhancements (as described in Section 2.3). It incorporates the most successful actions from the previous model and introduces new actions tailored to the needs of the new consortium.

The DEETECHTIVE project ("Deep Tech Talents—Innovation & Entrepreneurship Support"), funded with EUR 0.75 million from the KIC—EIT RAW Materials, started in May 2023 and ends by July 2024. All five HEIs utilized the HE Innovate self-reflection tool to assess their innovative potential. The results of this assessment are displayed in Table 4.

Table 4. DEETECHTIVE—Initial assessments.

Key Areas	WUST	HIT	UNIGE	EPF	CENT	Average
Leadership and Governance	2.2	4.8	1.2	3.8	3.0	3.0
Organizational Capacity: Funding, People, and Incentives	1.2	3.8	2.6	2.8	3.8	2.8
Entrepreneurial Teaching and Learning	2.2	3.8	2.0	3.6	4.2	3.2
Preparing and Supporting Entrepreneurs	2.3	4.5	2.7	3.0	3.5	3.2
Digital Transformation and Capability	2.2	4.0	2.8	4.0	4.0	3.4
Knowledge Exchange and Collaboration	1.8	4.6	3.2	4.0	4.0	3.5
The Internationalized Institution	1.6	4.4	4.6	3.4	4.0	3.6
Measuring Impact	1.5	3.7	2.5	3.0	2.5	2.6

3.3.1. DEETECHTIVE Model Implementation

HIT and EPF stood out in their initial assessments for their strong "leadership and governance", which enabled effective strategic direction and decision-making. Conversely, UNIGE and CENT had room for improvement, presenting opportunities to enhance their leadership initiatives.

In "Organizational Capacity", CENT excelled due to effective resource allocation and incentive structures, while WUST and UNIGE showed potential for improvement to boost their capacity.

CENT also led in "Entrepreneurial Teaching and Learning", creating environments that foster student innovation and creativity. WUST and UNIGE had the opportunity to refine their approaches to promote entrepreneurship further.

Regarding "Preparing and Supporting Entrepreneurs", HIT and EPF excelled with comprehensive support programs. WUST and UNIGE could benefit from strengthening their support systems for entrepreneurial ventures.

About "Digital Transformation and Capability", CENT showcased its expertise, utilizing technology to drive innovation. WUST and UNIGE, meanwhile, could enhance their digital capabilities to better adapt to evolving trends.

CENT also led in "Knowledge Exchange and Collaboration", indicating strong connections with industry and academia. WUST and UNIGE were encouraged to improve their collaborative efforts to leverage external expertise and resources more effectively.

Regarding "Internationalization", UNIGE and CENT displayed a strong international presence, fostering diverse perspectives and innovation opportunities. WUST and EPF were advised to expand their international collaborations to increase global impact.

Regarding "Measuring Impact", all HEIs needed to develop more robust evaluation frameworks to assess the effectiveness of their innovation initiatives.

Overall, WUST had the potential for broad improvements across several areas. HIT excelled in supporting entrepreneurship and showed strong leadership but could improve entrepreneurial teaching and impact measurement. UNIGE and EPF demonstrated capabilities in internationalization and supported entrepreneurs, although they could bolster their impact measurement and collaborative efforts. CENT performed well across multiple areas but had room to improve impact measurement.

The DEETECHTIVE project included seven key actions, with each partner involved in specific actions (Table 5) according to the results of the innovativeness potential assessment (Table 4).

Table 5. Participation in the DEETECHTIVE actions.

	Participation in Particular Actions	WUST	HIT	UNIGE	ITT	EPF	CENT
A.1	Talent Hunter Space	✔	✔	✔	✔	✔	✔
A.2	Deep Tech Dates	✔	✔	✔	✔	✔	✔
A.3	International Open Innovation Training: IDEA-up DEEP TECH	✔	✔	✔		✔	✔
A.4	Deep Tech innovation challenges	✔	✔	✔	✔	✔	✔
A.5	Pre-Incubation Mentoring Program "GROW UP TECH"		✔		✔	✔	
A.6	Start-up booster				✔		✔
A.7	Knowledge hotspot	✔	✔	✔	✔	✔	✔

All project activities are precisely defined and quantified, organized into two phases: Phase 1, from May to December 2023, and Phase 2, from January to July 2024. The structure of the actions—their number and length—results from the call requirements. The detailed breakdown of the KPIs is disclosed below (Table 6).

Some key results of the DEETECHTIVE implementation are supporting these KPIs.

Table 6. DEETECHTIVE—Planned KPIs.

IDEATION KPIs	Phase 1	Phase 2	Overall
Start-ups/scale-ups supported	2	3	5
Students trained with a view to innovation and entrepreneurship	360	365	725
Students mentored	36	39	75
Academic staff members trained with a view to innovation and entrepreneurship	60	72	132
Academic staff members mentored	18	21	39
Non-academic staff (e.g., professional staff, support staff) trained with a view to innovation and entrepreneurship	60	72	132
Non-academic staff mentored	18	21	39
Improved support structures and mechanism	7	10	17
New partnerships established	1	2	3
Start-ups created	0	1	1

3.3.2. Talent Hunter Space

Developed as a pan-European platform, Talent Hunter Space (THS) identified hidden talents among Deep Tech students. It allowed companies to register their Deep Tech needs and enabled academic teachers to recommend talented students to university units like career offices or business incubators. This process could integrate with the Moodle platform or function directly through THS, ensuring talents were matched with appropriate opportunities.

3.3.3. Deep Tech Dates Events

These new events were designed to strengthen partnerships within the knowledge triangle and create new networks focused on Deep Tech.

3.3.4. Open Innovation Training IDEA-Up DEEP TECH

This comprehensive online training program consisted of eight modules aimed at enhancing skills in entrepreneurship, innovation, and specific Deep Tech areas:

- Module 1: Entrepreneurship from the Deep Tech Point of View (three lectures);
- Module 2: Innovation and Entrepreneurship Capacity Building (eight lectures);
- Module 3: Business Models (two lectures);
- Module 4: Start-up Perspective (four lectures);
- Module 5: Deep Tech: Artificial Intelligence Insights (six lectures);
- Module 6: Deep Tech: Robotics (nine lectures);
- Module 7: Deep Tech: Additive Manufacturing (three lectures);
- Module 8: Deep Tech in Higher Education (two lectures).

3.3.5. GROW-Up TECH Pre-Incubation Program

Similarly to the implementation of this pre-incubation program in IDEATION (Section 3.2.6), which was complemented by the IDEA-up DEEP TECH training, GROW-up TECH supported the creation of start-ups in Deep Tech fields. It offered a practical alternative to traditional corporate careers.

3.3.6. Innovation Challenges and Start-Up Booster

Validated the innovation support model from the SYNERGY and IDEATION projects through innovation challenges based on crowdsourcing, accelerating the creation of new products. The new start-up booster model also supported Deep Tech start-ups by developing a dedicated transformation plan and a range of services.

These components of the DEETECHTIVE project implementation collectively aimed to improve innovation capabilities, foster entrepreneurship, and enhance the development of Deep Tech sectors across multiple institutions and networks.

3.4. Overall Assessment of IDEATION and DEETECHTIVE Implementation

This analysis of Phase 1 (July 2022–December 2022) and Phase 2A (January 2023–December 2023) for Project IDEATION revealed a resounding success in achieving key performance indicators (KPIs). Table 7 showcases not only the fulfillment but, in some instances, the surpassing of established performance goals. This achievement signifies a robust implementation of the project's IDEATION and DEETECHTIVE frameworks.

Table 7. IDEATION—reached KPIs in Phase 1 and Phase 2A.

IDEATION KPIs	Phase 1 Planned	Phase 1 Reached	Completion Rate (%)	Phase 2A Planned	Phase 2A Reached	Completion Rate (%)
Start-ups/scale-ups supported	3	3	100	3	3	100
Students trained with a view to innovation and entrepreneurship	260	313	120	375	494	132
Students mentored	22	39	177	30	33	110
Academic staff members trained with a view to innovation and entrepreneurship	60	76	127	75	152	203
Academic staff members mentored	8	8	100	8	17	213
Non-academic staff (e.g., professional staff, support staff) trained with a view to innovation and entrepreneurship	60	67	112	75	135	180
Non-academic staff mentored	8	9	113	8	16	200
Improved support structures and mechanism	19	19	100	33	34	103
New partnerships established	1	4	400	1	6	600
Start-ups created		0	0		1	25

The IDEATION project witnessed a remarkable display of collaborative efforts and innovation. Therefore, a breakdown of the key actions implemented is critical to understanding how the challenges were handled correctly.

The "Digital Access to Infrastructure" action involved all the project partners in establishing a successful mechanism for infrastructure sharing. This involved registering numerous infrastructures (101) and facilitating knowledge dissemination through presentations (5) on the sharing economy model. Furthermore, project efforts led to the creation of successful matches (4) between entities seeking and offering infrastructure access.

A cornerstone of IDEATION relied on the action "Knowledge Triangle Networks" aimed to foster new partnerships and strengthen existing collaborations. This was achieved by organizing well-attended Open Seminars (5) for 116 participants. A dedicated platform was also established, registering many entities (79) to foster ongoing collaboration.

Moreover, "Crowd Innovation" aimed to unleash student entrepreneurial and innovation potential. The project actively encouraged students to tackle real-world challenges by developing innovative solutions. This resulted in the creation of five compelling Innovation Challenges, which subsequently received student submissions (15) showcasing their ingenuity.

Then, by "Testing Crowdfunding Opportunities", IDEATION teams (WUST, ULL, and FIR) tried to unveil crowdfunding's capabilities, focusing on educating participants (students and staff) on the exciting world of crowdfunding and crowd-investing. Three comprehensive training courses were organized, reaching 90 participants. This newfound knowledge was translated into action with the development of 10 crowdfunding campaigns poised to unlock new funding opportunities.

As an additional substantial action of IDEATION, the "pre-incubation program" implemented by WUST, ULL, and CRIT aimed to nurture the next generation of startups. Thus, this action provided crucial support for budding entrepreneurs. Through 15 workshops, 36 participants received valuable guidance. Notably, the program successfully supported the launch of three promising startups.

Furthermore, as an international project, the "International Open Innovation Training IDEA-up", implemented by WUST, HIT, ULL, and FIR, was particularly impactful, attracting 381 registrants interested in delving into the world of open innovation. By the program's conclusion in December 2022, a significant portion (185) had successfully completed the training, signifying a strong commitment to innovation on a global scale.

As summarized in Table 8, KPIs established for Phase 1 were not only met but, in some cases, surpassed. This initial success lays a strong foundation for the project's continued progress.

Table 8. DEETECHTIVE—Planned and reached KPIs in Phase 1.

DEETECHTIVE KPIs	Phase 1 Planned	Phase 1 Reached	Completion Rate (%)
Start-ups/scale-ups supported	2	2	100
Students trained with a view to innovation and entrepreneurship	360	364	101
Students mentored	36	39	108
Academic staff members trained with a view to innovation and entrepreneurship	60	106	177
Academic staff members mentored	18	24	133
Non-academic staff (e.g., professional staff, support staff) trained with a view to innovation and entrepreneurship	60	89	148
Non-academic staff mentored	18	19	106
Improved support structures and mechanism	7	11	157
New partnerships established	1	2	200
Start-ups created	0	0	0

The various actions implemented within the project and their related achievements focus on nurturing deep tech talent, fostering innovation, and establishing collaborations.

By looking at the "Talent Hunter Space" action, in which all the partners were involved, a prototype IT solution was developed to help academic and non-academic staff identify innovative and entrepreneurship-oriented students (also called "talented students" herein). Six training sessions were organized to enhance the efficiency of the identified talented students. Mentoring was provided to 19 non-academic and 24 academic staff members. Additionally, 26 deep tech needs were registered, and 54 talents were identified.

Moreover, the main objective of the "Deep Tech Dates" was to facilitate collaboration by organizing six events (473 participants) and establishing a dedicated platform for ongoing interactions (50 entities registered). Additionally, training sessions enhanced skills for 149 participants (70 non-academic, 79 academic staff).

The "International Open Innovation Training: IDEA-up DEEP TECH" attracted a significant international audience (390 registrants) for deep tech open innovation training, and 364 (93.3%) participants successfully completed the program, showcasing a strong commitment to innovation.

To ignite student creativity, the project organized 10 "Deep Tech Innovation Challenges". These challenges inspired students, as evidenced by the 16 innovative solutions they submitted.

The "Pre-Incubation Mentoring Program GROW-up TECH" was established to nurture future deep tech leaders and support 39 aspiring deep tech entrepreneurs. Implemented by

ITT, EPF, and CENT, this program provided valuable guidance through nine workshops and dedicated mentoring.

A fruitful collaboration between ITT and CENT, entitled "Start-up Booster", empowered two promising deep tech startups. This program provided individualized incubation plans and dedicated services, giving them the tools they need to thrive.

The IDEATION and DEETECHTIVE projects were implemented in multiple phases, with IDEATION divided into three phases (Phase 1, 2A, 2B) and DEETECHTIVE into two (Phase 1 and 2). The division into phases resulted from the call requirements. This paper addresses the results of the three completed phases: IDEATION Phase 1, IDEATION Phase 2A, and DEETECHTIVE Phase 1. Additionally, it is worth noting that IDEATION was designed as a two-year project, while DEETECHTIVE was only a 15-month project with a significantly lower budget, which made DEETECHTIVE's implementation much more ambitious and challenging. In the completed phases of IDEATION, significant success was achieved in meeting the key performance indicators. The project consistently supported the target number of start-ups and scale-ups, with three supported in each phase. Thesummary of the KPIs achieved can be seen in Table 9. Student training exceeded targets, with 807 students trained in total in Phase 1 and 2A. Student mentorship also surpassed goals, with 72 students mentored in Phases 1 and 2A. Additionally, academic staff training achieved 127% of the target in Phase 1 and 203% in Phase 2A, while non-academic staff training exceeded targets, reaching 180% in Phase 2A. The project far surpassed targets for new partnerships, establishing 10 new partnerships in both finalized phases. DEETECHTIVE Phase 1, building on the IDEATION model, also showed promising results. It met the target for supporting start-ups and scale-ups, trained 364 students, and mentored 108% of the target number of students (39). Academic staff training achieved a completion rate of 177%, while non-academic staff training reached 148% of the target. The project established new partnerships at twice the targeted rate. Overall, the successful implementation of both IDEATION and DEETECHTIVE models highlights their effectiveness in fostering innovative environments within participating HEIs and the broader business community. In total, 1171 students and 655 HEI staff members have been trained so far, and 64 support structures and mechanisms have been established, including innovation challenges, successful infrastructure sharing, and crowdfunding campaigns. These initiatives increased entrepreneurial activity, enhanced training and mentorship, and strengthened international collaboration through numerous new partnerships. The IDEATION and DEETECHTIVE projects have laid a strong foundation for continued growth and impact in future phases.

Table 9. IDEATION and DEETECHTIVE—summary of the KPIs achieved.

KPIs	DEETECHTIVE Completion Rate (%)	IDEATION Completion Rate (%)	Total No. of KPIs Achieved
Startups/scale-ups supported	100	100	8
Students trained with a view to innovation and entrepreneurship	101	127	1171
Students mentored	108	138	111
Academic staff members trained with a view to innovation and entrepreneurship	177	169	334
Academic staff members mentored	133	156	49
Non-academic staff (e.g., professional staff, support staff) trained with a view to innovation and entrepreneurship	148	150	291
Non-academic staff mentored	106	156	44
Improved support structures and mechanism	157	102	64
New partnerships established	200	500	12
Startups created	n/a	25	1

4. Discussion

4.1. Main Findings

The IDEATION and DEETECHTIVE models have successfully fostered more innovative environments within local ecosystems, benefiting the participating HEIs and the broader business community. A literature review indicates a lack of existing infrastructure-sharing solutions aligned with the sharing economy's principles. IDEATION's Action 1, "Digital Access to Infrastructure", addressed this gap, which utilized the SYNERGY platform to facilitate infrastructure sharing. The implementation of both models confirms their effectiveness in promoting innovation within local ecosystems. It suggests that many actions could apply to various stakeholders, including SMEs and startups.

4.2. Strength and Limitations

The showcased projects exhibited notable strengths, particularly in strong international collaboration and multidisciplinary partnerships. Diverse perspectives from various cultural backgrounds facilitated rich cross-cultural exchanges that significantly enhanced the innovation process. The integration of unique ideas and approaches from these collaborations led to more innovative and comprehensive solutions. For instance, cross-cultural teams are more likely to generate creative outcomes due to the diversity of thought and problem-solving strategies they bring to the table. Similarly, the involvement of experts from different academic disciplines stimulated creativity by combining various methodologies and expertise, ensuring a holistic approach to addressing complex problems and making solutions more robust and well-rounded [58]. Thus, multidisciplinary teams are better equipped to tackle complex issues because they draw on a broader range of knowledge and techniques [59].

Moreover, the comprehensive problem-solving achieved through the involved consortia and their participants demonstrated that teams with diverse academic backgrounds produce more innovative solutions compared to homogenous teams. These strengths underscore the importance of fostering international and multidisciplinary collaborations in driving innovation and addressing complex global challenges effectively [60].

The IDEATION and DEETECHTIVE projects faced several limitations that impacted their effectiveness and posed significant challenges to achieving their goals. One of the primary issues was the traditional departmental structures within institutions. These structures often created organizational silos, which hindered collaboration by restricting the flow of ideas and resources across different fields. As a result, interdisciplinary cooperation was significantly impeded, making it difficult to leverage the full potential of diverse expertise and viewpoints.

Additionally, the necessity of coordinating efforts across various time zones and aligning the schedules of international partners required meticulous planning and robust management strategies. This posed substantial management challenges, as it was essential to ensure that all parties remained on track and that project timelines were adhered to. The complexity of managing such widespread collaboration often led to delays and inefficiencies, highlighting the need for more agile and adaptive management practices.

Another significant limitation was the disparity in innovation culture among the collaborating entities. Different organizations and teams had varying approaches and attitudes toward innovation, which necessitated considerable efforts to align these differences. Harmonizing expectations and working styles was crucial to fostering a cohesive working environment, but it also required time and resources that could otherwise have been spent directly on innovation activities.

Logistical and communicative challenges further compounded these issues. Misaligned academic calendars across different countries made it difficult to synchronize project milestones and deadlines. This lack of synchronization often resulted in periods of inactivity or misalignment in project phases, which could delay progress and reduce overall efficiency. Furthermore, language barriers presented additional obstacles to effective communication. The need for translation and interpretation services to ensure clear and accurate exchanges of ideas and information added another layer of complexity to the projects. These language barriers sometimes led to misunderstandings and miscommunications, which could further hinder collaboration and slow down project advancements.

In summary, while the projects had the potential to benefit significantly from international and interdisciplinary collaboration, they were also challenged by traditional departmental structures, the complexities of managing across time zones, disparities in innovation culture, and various logistical and communicative barriers. Addressing these limitations required strategic planning, adaptive management, and concerted efforts to align diverse teams and resources.

In summary, while the projects capitalized on the strengths of international collaboration and multidisciplinary partnerships to drive innovation and comprehensive problem-solving, they also had to address significant limitations related to structural, managerial, cultural, and logistical challenges [58,61,62].

4.3. Future Perspectives

Given the strengths and weaknesses observed, several strategies could enhance future projects:

- Enhanced Cross-Institutional Collaboration: Future initiatives should focus on developing standardized collaboration frameworks that facilitate knowledge sharing and resource pooling across institutions and disciplines;
- Streamlined Infrastructure Sharing Solutions: Building on the successful implementation of Digital Access to Infrastructure, future projects could develop more sophisticated platforms that leverage technologies like blockchain for efficient and secure resource sharing;
- Cultural Integration and Inclusivity Initiatives: Addressing cultural and language barriers is crucial. Future projects include language exchange programs and cultural sensitivity training to foster effective international collaboration;
- Flexible Time Management Strategies: Implementing flexible and dynamic project management frameworks could accommodate varying institutional schedules, enhancing project coherence and effectiveness;
- Improving the inclusion of all stakeholders to increase innovation interest by adding end-users and developers, as illustrated for innovation for persons with disabilities [63];
- Continued Emphasis on Multidisciplinary Collaboration: Future projects should continue to encourage collaboration across diverse fields, using approaches like interdisciplinary research programs and collaborative innovation hubs to address complex challenges holistically, such as the One Digital Health framework [64]. By breaking down silos and promoting cross-pollination of ideas, future initiatives can unlock new opportunities for innovation and create positive impact across various sectors and domains.

To sum up, the IDEATION and DEETECHTIVE projects have showcased the potential for innovative models to enhance the capabilities of higher education institutions significantly and set a benchmark for future collaborative efforts across various ecosystems. By addressing the key challenges and building on the strengths identified through these projects, future initiatives can be better designed to foster an inclusive, collaborative, and technologically advanced environment. Embracing these strategies will enhance the impact of innovation projects and ensure they are resilient and adaptable to the changing demands of global education and business landscapes. The journey of continuous improvement and adaptation in higher education innovation practices promises to unlock profound transformations, paving the way for a future in which academia and industry collaboratively thrive on creativity and technological advancement. The IDEATION and DEETECHTIVE models have shown their potential in transforming higher education institutions into hubs of entrepreneurial and innovative activity. Future research and practical applications could be significantly advanced by aligning with the Deep Tech Talent Initiative, a flagship under the New European Innovation Agenda, driven by the EIT, aiming to train 1 million people in deep tech areas. Future research directions will focus on how the IDEATION and DEETECHTIVE models can be adapted to integrate training modules from the Deep Tech Talent Initiative, including developing specialized curriculum components for advanced topics like artificial intelligence and blockchain technology. Studies could evaluate the impact of these integrated models on local and regional innovation ecosystems, using metrics such as the number of startups created, industry-academia collaboration levels, and local economic impact. Research could also explore the scalability of these models across different European regions and their transferability to other global contexts, assessing their adaptability to various educational and cultural environments. Practical applications could involve establishing deep tech hubs that serve as incubators for high-tech startups, building on the foundation laid by IDEATION and DEETECHTIVE. Enhanced collaboration platforms could be developed to facilitate better communication and resource sharing among stakeholders in the deep tech ecosystem, leveraging advanced technologies for improved security and efficiency. Institutions could also develop and offer customized training programs aligned with the goals of the Deep Tech Talent Initiative, ensuring that students and professionals are equipped with the skills needed to thrive in a rapidly evolving technological landscape. By integrating the IDEATION and DEETECHTIVE models with the objectives of the Deep Tech Talent Initiative, future research and practice can significantly contribute to positioning Europe as a leader in deep tech innovation. This alignment supports training a new generation of skilled professionals and fosters a robust, collaborative, and inclusive innovation ecosystem.

5. Conclusions

We developed and validated the IDEATION and DEETECHTIVE models within real-world contexts to transform higher education institutions (HEIs) into entrepreneurial and innovative activity hubs, significantly enhancing their impact on surrounding ecosystems. These models incorporate entrepreneurship, deep tech, open innovation, the sharing economy, and social product development. They respond to the dynamic shifts in work styles, innovation paradigms, and educational landscapes driven by Industry 4.0/5.0, the pervasive influence of social media, and the ongoing impacts of the COVID-19 pandemic. This study aimed to create an innovative model that promotes entrepreneurship among engineering and science students, emphasizing global collaboration.

During the IDEATION and DEETECHTIVE projects, we reached our goals and answered our research questions by validating our hypotheses. Thus, the strategies we have developed and implemented to increase the number of engineering and science student entrepreneurs inside HEIs mainly involve the development of continuous mentorship programs that provide large access to entrepreneurship resources. By doing so, students can receive guidance and support in turning their ideas into entrepreneurial ventures. In addition, incorporating online education and open innovation topics into the curriculum significantly improves students' entrepreneurial skills and outcomes. This approach allows students to engage with a wider range of resources and perspectives, fostering a deeper understanding of entrepreneurship. Our findings support the hypothesis that online education and open innovation are crucial components of an effective innovation model for enhancing entrepreneurship within HEIs. The integration of these elements helps in creating a more flexible and accessible learning environment, which is essential for nurturing innovative ideas and entrepreneurial skills.

Furthermore, international collaborations have been shown to foster a globally-minded entrepreneurial mindset among students and HEIs staff members. HEIs that actively engage in international collaborations report higher levels of entrepreneurial activity and innovation among their students. These collaborations provide students with unique opportunities to learn from diverse perspectives, engage in cross-cultural problem-solving, and develop a global network. Our research supports the hypothesis that international collaborations are crucial in promoting entrepreneurship and innovation within HEIs. By facilitating regular cross-institutional workshops and networking events, we have strengthened international collaborations and fostered a more globally-minded entrepreneurial mindset among students. Initiatives that can be undertaken to develop a new generation of innovative and entrepreneurial engineers and scientists within HEIs include integrating practical, real-world projects into the curriculum. This approach enables students to apply their knowledge and skills to real-life scenarios, fostering innovation and an entrepreneurial mindset. In conclusion, the IDEATION and DEETECHTIVE projects have demonstrated the effectiveness of these strategies and initiatives in fostering entrepreneurship within HEIs. By implementing these approaches, HEIs can significantly enhance their students' entrepreneurial skills, foster innovation, and contribute to the development of a new generation of innovative and entrepreneurial engineers and scientists.

The IDEATION model underwent thorough testing, evaluation, and refinement, evolving into the more comprehensive DEETECHTIVE model. This progression has significantly enriched academic discourse by enhancing theoretical foundations for crafting student-centric innovation models that foster entrepreneurship within these fields. Additionally, this study explores the models' transferability, illustrating how other HEIs, companies, and business support organizations might adopt these innovative approaches. Despite various challenges, the IDEATION and DEETECHTIVE models have effectively accelerated innovation at participating HEIs, achieving ambitious objectives swiftly. This research introduces a new, validated framework that empowers HEIs to cultivate a culture of entrepreneurship and innovation, thereby nurturing ecosystems rich in creativity and advancement.

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Abbreviations

CENT	Centria University of Applied Sciences
EIT	European Institute of Innovation and Technology
EPF	EPF School of Engineering
HEI	Higher Education Institution
HIT	Holon Institute of Technology, Israel
FIR	Institute for Industrial Management, Germany
KIC	Knowledge and Innovation Community
KPI	Key performance indicator
OI	Open Innovation
OI2	Open Innovation 2.0
QHIM	Quintuple Helix Innovation Model
SPD	Social Product Development
THS	Talent Hunter Space
ULL	University of La Laguna, Spain
UNIGE	University of Genova
WUST	Wroclaw University of Science and Technology

Appendix A. Key Performance Indicators (KPIs) Segmented by Actions

Table A1. IDEATION—planned KPIs segmented by actions.

KPIs per Action in IDEATION: Phase 1	**A.1**	**A.2**	**A.3**	**A.4**	**A.5**	**A.6**	**Sum of KPIs**
Improved support structures and mechanism	5		5	9			19
Academic staff members trained with a view to innovation and entrepreneurship		25		15		20	60
Academic staff members mentored						8	8
Non-academic staff (e.g., professional staff, support staff) trained with a view to innovation and entrepreneurship		25		15		20	60
Non-academic staff mentored						8	8
Startups/scale-ups supported					3		3
Students trained with a view to innovation and entrepreneurship				30	30	200	260
Students mentored					6	16	22
New partnerships established		1					1
KPIs per Action in IDEATION: Phase 2A	A.1	A.2	A.3	A.4	A.5	A.6	Sum of KPIs
Improved support structures and mechanism	5		10	18			33
Academic staff members trained with a view to innovation and entrepreneurship	15	25		15		20	75
Academic staff members mentored						10	10
Non-academic staff (e.g., professional staff, support staff) trained with a view to innovation and entrepreneurship	15	25		15		20	75
Non-academic staff mentored						10	10
Startups/scale-ups supported					3		3

Table A1. *Cont.*

KPIs per Action in IDEATION: Phase 2A	A.1	A.2	A.3	A.4	A.5	A.6	Sum of KPIs
Students trained with a view to innovation and entrepreneurship	35			30	30	280	375
Students mentored					6	24	30
New partnerships established		1					1
KPIs per Action in IDEATION: Phase 2B	A.1	A.2	A.3	A.4	A.5	A.6	Sum of KPIs
Improved support structures and mechanism	5		5				10
Academic staff members trained with a view to innovation and entrepreneurship	10	25					35
Academic staff members mentored							0
Non-academic staff (e.g., professional staff, support staff) trained with a view to innovation and entrepreneurship	10	25					35
Non-academic staff mentored							0
Startups/scale-ups supported					3		3
Students trained with a view to innovation and entrepreneurship	15				30	120	165
Students mentored					6	8	14
New partnerships established		1					1
Startups created							0

Table A2. DEETECHTIVE—planned KPIs segmented by actions.

Planned KPIs per Action in DEETECHTIVE: Phase 1	**A.1**	**A.2**	**A.3**	**A.4**	**A.5**	**A.6**	**Sum of KPIs**
Improved support structures and mechanism	1			6			7
Academic staff members trained with a view to innovation and entrepreneurship	30	30					60
Academic staff members mentored	6	12					18
Non-academic staff (e.g., professional staff, support staff) trained with a view to innovation and entrepreneurship	30	30					60
Non-academic staff mentored	6	12					18
Start-ups/scale-ups supported						2	2
Students trained with a view to innovation and entrepreneurship			360				360
Students mentored					36		36
New partnerships established		1					1
Planned KPIs per Action in DEETECHTIVE: Phase 2	A.1	A.2	A.3	A.4	A.5	A.6	Sum of KPIs
Improved support structures and mechanism	1			9			10
Academic staff members trained with a view to innovation and entrepreneurship	36	36					72
Academic staff members mentored	9	12					21
Non-academic staff (e.g., professional staff, support staff) trained with a view to innovation and entrepreneurship	36	36					72

Table A2. *Cont.*

Planned KPIs per Action in DEETECHTIVE: Phase 2	A.1	A.2	A.3	A.4	A.5	A.6	Sum of KPIs
Non-academic staff mentored	9	12					21
Startups/scale-ups supported						3	3
Students trained with a view to innovation and entrepreneurship			365				365
Students mentored					39		39
New partnerships established		2					2
Startups created						1	1

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Article

Digital Transformation and Teaching Innovation in Higher Education: A Case Study

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Abstract: The digital maturity of universities has been a key element in coping with the forced situation brought about by COVID-19 and in subsequent years. This research paper presents a case study of a private Spanish university that aims to analyze the challenges and opportunities that have arisen after the pandemic in terms of resource management and training for teaching innovation and digitization. The nature of this study is qualitative, in which nine interviews were conducted with managers from different faculties and those responsible for Information and Communication Technologies. After analyzing the data with Atlas.ti, four categories were established (technological resources and devices, challenges, opportunities, and others). The study concludes by discussing the commitment to online training, the popularization of videoconferencing tools for teaching sessions, meetings, or synchronous tutorials, and the acceleration of digital transformation, among others.

Keywords: remote teaching; COVID-19; technological resources; digital transformation; higher education; teaching innovation

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1. Introduction

Due to its potential impact and the relevance of digitization in the digital era on different areas (education included), digital transformation (DT) was thought to be a key opportunity as posited in multiple research works focused on the educational field (e.g., [1–3]). Diverse research works from varied points of view have focused on different aspects of DT in education in the post-pandemic period, such as identifying the critical elements to implement DT [4] and the barriers to its implementation in higher education institutions (HEIs) [5]; finding different digital DT initiatives in HEIs [6]; the impact of DT on education [7]; or how DT can impact the sustainability of HEIs [8]. Therefore, shedding light on specific issues related to DT constitutes a relevant topic in the future of education institutions.

News of a new virus that became known as SARS-CoV-2 began to emerge at the end of December 2019 in Southeast Asia. As the virus spread over time, the World Health Organization declared SARS-CoV-2 (COVID-19) as a global pandemic. According to UNESCO [9], 32 countries on three continents either announced or implemented school and university closures in early March 2020. Within days, more than 160 countries ordered school closures, which affected 1.5 billion children and young people [10], especially the most vulnerable. According to Marinoni et al. [11], in May 2020, around 67% of HEIs transitioned to online teaching, 24% suspended their classes while looking for solutions, and 7% cancelled their teaching processes altogether (the remaining 1% were not affected). While every effort was made to ensure pedagogical continuity by promoting a window of opportunity in terms of innovation and the adoption of technology, COVID-19 brought major challenges, such as engaging in distance teaching for the first time, increasing teachers' lesson planning workloads, gaps in connectivity and technological devices, and digital literacy, among others [12]. For most countries, the pandemic challenged education systems and accelerated DT, highlighting the need for new methodologies and approaches, infrastructure, access to connectivity, devices, digital platforms, learning resources, and digital skills, not to mention the human factors involved in transforming education [9].

In Spain, because of the health crisis, a state of emergency was declared in mid-March 2020 (by Royal Decree 463/2020, of March 14, declaring a state of alarm for the management of the health crisis situation caused by COVID-19) [13]. This piece of legislation brought about the imminent closure of the physical facilities of universities, and therefore gave rise to the need to seek new alternatives to enable the teaching–learning process to continue, in order to guarantee the academic and professional training of students in HEIs [14–17]. Spanish universities directly suffered the impact of the pandemic and were able to provide solutions and response mechanisms in a very short period of time. As reported in 2020 by CRUE [18] (a non-profit association that groups a total of 76 Spanish universities, both public and private), Spanish universities faced the challenges of using technology to innovate teaching, improve virtual laboratories and staff training in digital skills, and enhance issues related to data protection and assessment.

This research paper presents a case study that aims to analyze the challenges and opportunities that arose after the COVID-19 pandemic period in a private university in Spain, which is measured in terms of resource management and training for teaching innovation and digitization. This research examines the institution's management vision regarding its DT, as part of a triad of studies. Additionally, this comprehensive research includes a study on the teaching staff's perspective, particularly their acceptance or rejection of technology in the classroom [19], along with ongoing research focusing on student perceptions, well-being, and technology. The theoretical framework will succinctly outline several factors that contextualize the issues under study from a multifaceted perspective. This will be followed by a description of the research methodology used and a summary of the findings. Finally, these findings will be discussed, and the paper's conclusions will be presented.

2. Theoretical Framework

The suspension of face-to-face classes and the start of lockdown forced educators and students to rapidly use different Information and Communication Technologies. This situation was seen both as an opportunity [20] and a challenge [21], due to the shortfalls in infrastructure, training, and connectivity on the part of universities [22] and students. In order to overcome the digital divide, the Spanish government recommended improving universities' computer equipment and online networks, as well as training teaching staff in the use of digital communication and connectivity.

The pandemic was both a challenge and an opportunity for teaching staff at all educational levels, since it required the development of new skills in the use of digital devices and programs, curriculum adaptations, and even innovation in educational processes in order to ensure the acquisition of knowledge and the development of competences by students [23,24]. According to Satorre Cuerda [25], the fact that this compelling situation occurred overnight accelerated the implementation of didactic innovations and different modes of teaching that were hitherto only theories and intents. Numerous research articles have focused on different specific aspects, such as the shift from face-to-face training on university campuses to remote training (e.g., [26–31]), analyzing various specific issues arising from not being physically present in the classroom (e.g., [32–35]), the implications for the well-being of those concerned [36–40], or the new opportunities arising in education from the adoption of remote or hybrid formats (e.g., [41–43]).

In Spain, despite the digital advances driven by COVID-19, according to Gómez [44], 71% of HEIs consider themselves digitally distressed, as 'digital maturity is a gradual process that unfolds throughout the organisation over time, no organisation can become digitally mature overnight' (p. 10). However, according to the 2022 UNIVERSITIC report [45], digital maturity in Spanish universities has improved since 2020, because during this period, they had a budget of EUR 142,85 million promoted by the UniDigital Plan of the Ministry of Universities [46] to digitize the university system, and university leaders have understood the importance of increasing digital maturity for their institutions to be competitive in a digital and rapidly changing environment. In recent years, innovative teaching initiatives and classrooms with advanced technological equipment have been promoted, which have included offering online classes in real time and redesigning classrooms and laboratories.

Fernández et al. [6] conducted a literature review of the DT initiatives that universities have carried out and concluded that the most of the emerging technologies used included advanced analytics (23%), servers (20%), and artificial intelligence (16%). They highlighted that HEIs in Spain are merely taking their first steps towards digital maturity, as only one in four institutions have a detailed digital strategy in place.

Various frameworks exist in the literature for assessing the digital maturity of universities. For example, Molina-Carmona et al. [47] proposed the MD4U model with seven strategic challenges that any university should consider if they are to increase their digital maturity and improve their strategic processes. These challenges are as follows: expanding digital skills and culture among the university community; optimizing information security and maintaining business continuity; being competitive thanks to the high quality of services provided; offering high quality, competitive education; meeting the emerging demands of clients (students); having information and knowledge for optimal decision-making; and achieving the university's strategic objectives (vision).

3. Objectives and Methodology

The university that is being analyzed in this case study provided teaching remotely from 14 March until the end of the 2019–2020 academic year. The following academic year, 2020–2021, it returned to face-to-face teaching, but with safety measures: setting a limited ratio of students per class, leaving some free seats between students, an obligation to wear masks indoors, and ensuring good ventilation. In degree courses with a large number of students, the full classes were divided into two groups. The students in these groups attended classes on alternate days in person, and one of the sessions for each subject took place with the whole group remotely. Finally, in the 2021–2022 academic year, the course returned to full in-person attendance.

The research question of the study is as follows: how has the digital transformation implemented by a private university in Spain during the period 2019–2022 influenced its ability to address post-pandemic challenges and leverage new opportunities? Therefore, the overall objective of this research is to present a case study of a private university in Spain in which the post-pandemic challenges and opportunities are analyzed on the basis of the measures implemented at the time to minimize and combat the effects of COVID-19.

The analyzed university has more than 130 years of experience and offers a wide variety of degrees, double degrees, master's degrees, and doctoral degrees in the fields of Business, Law, Health Sciences, Psychology, Sports, Education, Social Sciences, Theology, Languages, and Communication. More than 12,000 students were enrolled in the 2023–2024 academic year, and more than 1600 employees were involved.

This research is based on a case study methodology using a qualitative approach. This methodology was used because the research sought to understand and gain in-depth knowledge of a specific situation, consistent with a case study approach [48]. Specifically, this work focuses on the analysis of digital transformation in a post-pandemic scenario from the point of view of the university's ICT managers and leaders. A total of nine interviews were carried out: five of them with the managers of the different faculties, one with the Pro-Vice-Chancellor for Academic Affairs, one with the Information Technology support staff, one with the manager of the Online Training Unit, and another one with the person in charge of the Teaching Innovation Unit. These participants were selected because they had an insider's view of the institution and because they were responsible for many decision-making processes. These staff members were sent an email that requested their participation, and those who did not respond were reminded by telephone. Table 1 includes further details of the participants, who are identified with the labels P1 to P9.

Table 1. Detail of the participants in the study.

Participants	Position	Sex
P1	Manager of the Faculty of Economics	Male
P2	Manager of the Faculty of Social Sciences and Humanities	Female
P3	Manager of the Faculty of Education and Sport, and Health Science	Male
P4	Manager of the Faculty of Law	Male
P5	Manager of the Faculty of Engineering	Male
P6	Pro-Vice-Chancellor for Academic Affairs	Female
P7	IT Support	Female
P8	Online Training Unit	Female
P9	Teaching Innovation Unit	Male

Semi-structured in-depth interviews were used to collect the data. They included the following questions, which revolved around resource management, challenges, and opportunities, and their effects on digital transformation:

1. What digital technology resources have been available to the faculty since the beginning of the pandemic?
2. Which kind of technological support devices have been acquired by the faculty?
3. How have technological support devices been managed?
4. What challenges and opportunities have you seen with regard to the use of digital technology in teaching?

The interviews were conducted from October 2022 to December 2022. In order to improve validity, the interviews were recorded to obtain the verbatim narratives of the participants. They were analyzed and verified by three researchers using the Atlas.ti software, version 9. The interviews lasted an average of 25 min.

The participants were at all times aware of the ethical principles of confidentiality, anonymity, privacy, and free choice of participation. They were also informed about the purpose of the research.

A deductive coding technique was used, that is, the initial categories were determined prior to data collection based on the interview script. While these were supported by the previous literature, emerging codes and categories were also created [49].

4. Results

A categorical content analysis was carried out. Based on a total of one-hundred and fourteen interview excerpts, four categories and twenty-seven codes were assigned.

A fast way to obtain an overview of the interview content is by creating a word cloud or word list. After using filters to exclude words such as prepositions and determiners, the most mentioned terms were as follows: pandemic, online, education, university, educators, changes, cameras, meetings, and face-to-face.

The most significant root codes (the most represented codes) were related to cameras (N = 13), hybrid classrooms (N = 13), and licenses (N = 7). A table that details the categories and codes is presented below (Table 2):

Table 2. Interview categories and codes.

Categories	Codes	Root Codes (N)
Technological resources and devices	Cameras	13
	Camera lights	6
	Licenses	7
	Laptop computers	4
	Interactive whiteboards	4
	Tablets	3
	Headphones	4
	Hybrid classrooms	13
	Google Meet	4
	Google Drive	4
	Website	2
	Forum	3
Challenges	Online education	4
	Emergency remote teaching	2
	Opening markets	2
	In-service training	6
	Low birth rate	5
	Assessment	1
	Legislation	2
Opportunities	Online Training	4
	Low birth rate	5
	Trust	4
	Remote meetings	5
	Peer network	5
	Optional webinars	4
Others	Management	2
	Teamwork	5

The categories and codes that emerged from the interviews are analyzed below:

(a) Technological resources and devices:

Before COVID-19, the analyzed university already had sufficient technological resources such as laptops for each member of the full-time teaching and research staff (known in Spanish as PDI), desktop computers for administration and service employees and some teaching and research staff members, software licenses, interactive whiteboards in some classrooms, loan laptops for teaching staff with temporary contracts, 360-degree cameras, and some hybrid classrooms. However, during the pandemic and afterwards, it was necessary to purchase new technological resources. Since most laptops have a built-in camera, it was not necessary to buy a lot of cameras; on average, about four to six cameras were required per faculty. However, a more significant disbursement was made for a widespread purchase of lollipop/giraffe 360-degree cameras with the support of the Vice-Chancellor's Office. These cameras were mainly used during COVID-19 for hybrid teaching, i.e., one subgroup was in the classroom for a face-to-face session while the members of the other subgroup were following the sessions from home. In the specific case of the Faculty of Law, P4 stated that there was a need to have technical support for the management of this kind of camera, allowing the professor to focus on teaching tasks. This issue was resolved with the help of a scholarship student, who was enrolled in a master's degree with a specialization in Information and Communications Technologies. Overall, the participants highlighted that the audio quality of these cameras was excellent for addressing the listener. Despite the large disbursement, after the return to normality, they were only used for some postgraduate meetings due to visa problems that made it difficult for certain students to attend the doctoral seminars.

In addition to the lollipop/giraffe cameras, light cameras, headsets, tablets, licenses (especially for the Screencast-O-Matic and Loom resources for video tutorials), and laptops were purchased during the COVID-19 period.

On the other hand, all participants rated Google Meet and Drive as the most used applications during the pandemic. P2 stated the following: 'For example, here at the faculty, don't ask me why, as luck would have it, we didn't work with Drive, we had everything in folders', but 'just before the pandemic we decided to save everything in Drive'. Moreover, during the pandemic, a website was created to collect all the information related to remote teaching, such as a forum to ask questions or share examples of good practices.

Finally, it is worth noting that hybrid classrooms existed before the pandemic. These spaces could be used by anyone, regardless of the faculty in which they were located. Strangely enough, 'the faculty of theology was a pioneer in all this' (P2). The aim of these rooms is that students who are away from the classroom can connect under the same conditions as those in the classroom. P8 argued that these 'spaces should be used for specific things that make sense in terms of length and time'. For example, these spaces could be used for talks between different campuses or doctoral courses, since 'it makes no sense for someone from Colombia to come to a three-hour doctoral seminar' (P8).

(b) Challenges:

One of the major challenges identified by the participants was online education. In future academic years, the analyzed university will offer two online degrees; to a certain extent, these have been streamlined and 'somewhat driven by the pandemic' (P1) and the low birth rate, although the design and planning process had already started two years before the COVID-19 crisis. Eighty percent of the participants believed that the online offering should be attractive and dynamic, and that great care should be taken in the design of the materials and the platform. Moreover, P5 argued that digital literacy is extremely important, as is the creation of engaging videos and video tutorials. According to P2, a key element was to have the ability to open up to the market and attract new students, as she believed that the university has a relatively local scope.

However, P2 was wary about online education, as she thought that a differentiating feature of this university is face-to-face education. P5 pointed out that the drop-out rate in some online degrees can be high, and therefore considered that it cannot be offered in all faculties.

Linked to the above ideas, P6 and P8 argued that the pandemic emergency meant that, 'everything was done in a hurry, and many did not have enough time, it was a bad experience', and that 'these points of reticence remain among the teaching staff'; therefore, it may be difficult to persuade some educators to teach an online degree.

Lifelong learning was also noted as a challenge. P3 noted that 'historically, the number of online in-service training courses has been quite low'. However, during the pandemic, both technology-savvy and reluctant teaching staff attended many of the webinars that were offered. The webinars that were most in demand were those on how to motivate students, keep them engaged, and prepare for online exams. With regard to this last aspect, P7 stressed that new sites with specific guidance on assessment were generated, as assessment was one of the most sensitive issues.

In addition, all the participants indicated that after the return to normality, many students asked for some classes, review work, and meetings to be held remotely for convenience, although the analyzed university decided not to change the regulations and to remain committed to face-to-face learning, except in exceptional cases.

Finally, it should be noted that strategy and leadership play a key role in the development of DT. This point was stated by P8: 'the route to DT depends on the leadership and strategy of the university (and its managers)'.

(c) Opportunities:

P3 stated that today's society is experiencing a profound decline in birth rates, and as a result, the number of teaching groups in each year in schools has been reduced, which is a problem that will certainly also reach universities in 8 to 10 years' time. To address this, participants agreed that educational institutions should gradually prepare for the online world, which would provide the opportunity to open new markets in the future.

All the participants mentioned that people have become much more confident with technology, to the extent that they have become used to holding meetings online, 'and this feels natural, they're not nervous in front of the cameras' (P5). Before the pandemic, most staff meetings took place in person, but since then, meetings between staff from the three campuses, the dean's team, and students (to review work and activities) have tended to be held online using MEET. In the opinion of the participants, virtual meetings are more practical and convenient, mainly because of the quality of the video and audio in web conferencing. However, P1 indicated that he preferred face-to-face meetings when there is a new teaching team.

Finally, all the participants noted that strong and positive peer relationships were generated. They added that the fact that attendance to webinars was optional was a great success.

(d) Others

The management of technological resources at this university was centralized from the Pro-Vice-Chancellor's Office during the COVID-19 crisis. All the interviewees pointed out that the university had made a strategic commitment to include online learning in its strategic plans since 2010; therefore, the pandemic did not have a very significant negative impact in terms of technological resources and infrastructure. They agreed that 'perhaps the greatest value of the university is that we worked really closely together as a team, the IT service, the Teaching Innovation Unit and the Online Education Unit' (P8). Moreover, since 2010, the university has been engaged in team efforts in this regard and the three units (IT Support, the Online Education Unit, and Teaching Innovation Unit) have been meeting regularly.

5. Discussion

This study delves into the challenges and opportunities related to resource management and training for teaching innovation and digitalization that have emerged in the post-pandemic years. This case study not only sheds light on the current state of digital maturity in higher education at a Spanish private university, but also highlights the critical steps universities are taking to adapt and thrive in a post-pandemic world.

García-Peñalvo (2021) stressed that the DT of universities requires changes along three lines: in management and governance (through strategic plans), in physical infrastructure (connectivity, servers, storage space, audio–visual content production, etc.), and in logical infrastructure [50].

Regarding the findings gathered about technological resources and devices, different ideas are detailed below.

Most of the participants agreed that a positive aspect was the popularization of videoconferencing tools for teaching sessions, meetings, and synchronous tutorials. However, we should not overlook the various difficulties that these tools can pose, such as those related to the pace of the class, problems with the interaction between educators and classmates, and issues linked to attention and procrastination, among others [33,35,43,50]. In reference to the software used, the widespread use of the Google Meet and Drive applications coincides with other studies, as stated in [48,51,52]. Finally, it should be noted that in this university, hybrid classrooms already existed before the pandemic; similarly, as implemented in other universities [53–55].

In this case study, the participants' responses have not made explicit reference to the need to continue boosting emerging technological trends such as artificial intelligence, the Internet of Things, blockchain technology, and other relevant platforms and technologies such as social media, mobile platforms, big data analysis, and cloud computing, Robotic Process Automation, Virtual Reality and Augmented Reality, and Additive Manufacturing, in contrast to the results of the study of Truong and Diep [56].

In connection with the Challenges and Opportunities categories, the findings show a majority consensus (80% of the participants) in leveraging the technological impulse to implement a greater offering of online education, especially for university degrees and in-service training. A firm commitment to this strategy is all the more necessary given the low birth rate in Spain. However, some of the participants interviewed were reticent to the upsurge in online education, mainly due to two factors: (i) the structural paradigm shift that is required, and (ii) the difficulty in overcoming a certain level of resistance from the teaching staff due to the distressing experience they had had during the ERT (emergency remote teaching) phase. These types of barriers are also described in other studies [3,5].

The United Nations Educational, Scientific, and Cultural Organization [57] has acknowledged that teachers play an essential part in the construction of inclusive, equitable, and quality education; therefore, in order to face the COVID-19 pandemic, it was necessary to develop skills in the use and management of Information and Communication Technology, reinforce remote teaching, and strengthen the morale and motivation of academics. Consistent with this need, the development of DT should be driven by the university's management structure in accordance with P8's comments.

It is worth highlighting a major idea expressed by the participants: the forced use of technology during the pandemic has increased the confidence in its use. In addition, ties between members of the university community have been strengthened. Therefore, these factors can facilitate the DT process at the university.

Finally, the findings of the study are aligned with those presented in the 2022 UNIVERSITIC study [45]. Firstly, the COVID-19 pandemic has accelerated the pace of digital transformation, which has been compared to the creation of the Internet, highlighting the extraordinary response by universities. In the analyzed case, this fact has been possible thanks to the measures adopted by the institution since 2010 (P6). Secondly, strategic planning is required to evolve towards a digital university paradigm; this involves transforming university processes to ensure that additional new students can be reached through a satisfactory experience that reinforces digital competences, which is in line with P8's comments. However, opportunities such as those brought about by artificial intelligence and threats such as cyber-attacks were virtually absent from the interviews. The 2022 UNIVERSITIC report urged universities to meet these challenges.

There are several contributions that study the pre-pandemic and pandemic scenario from the point of view of managers. Using a qualitative approach, this study brings together the perspectives of nine ICT university managers and leaders through in-depth interviews in a post-pandemic scenario. As Yin (2018) points out, case studies allow us to complement other types of studies that add data [48], such as the UNIVERSTIC study (2022), in the field studied [45]. Along these lines, Romero et al. (2023) highlight the need to collect information on digital transformation in universities from a qualitative perspective in the post-COVID-19 period, so that the lessons learned can be useful for other universities that want to embark on a similar path [58].

The findings of this case study are particularly useful for the institution analyzed. However, the implications of this research also extend to members of the university community and organizations involved in implementing DT in the educational field. On the one hand, a unique perspective on the same challenge has been obtained from different management roles. Furthermore, this managerial vision is part of a broader study that also analyses the perspectives of teaching staff [19] and students (study in progress), providing a multifaceted view of DT. Both the methodology used and the results obtained can serve as a foundation for new studies in other educational institutions undergoing DT processes.

One limitation of this research is that it is a case study in a specific context. Therefore, as part of future research, it would be interesting to conduct a longitudinal study with a larger sample of HEIs to analyze how their DT is progressing. Moreover, for future lines of research, it would be of interest to know the students' opinion on DT and even to replicate the same study in other universities, whether public and/or private, since the results may be different depending on the context.

6. Conclusions

This research work provides a business vision related to the adoption of technology in the university environment, at a time after the COVID-19 pandemic period. Therefore, this article outlines strategic reflections related to the adoption of technologies without the condition derived from restrictions imposed by the authorities. However, the changes forced by the pandemic have allowed us to draw a series of conclusions related to the use of technology. HEIs are no strangers to DT [59], but the road to it is often fraught with difficulties. As stated by Molina-Carmona et al. [47], DT is much more than digitization. Exploring it requires identifying the potential of technology to drastically transform business processes, create new services, or develop strategic business processes.

From this case study, it has been confirmed that there has been a DT strategy since 2010 that is detailed in the strategic plan and that the university has managers responsible for it. Furthermore, following the MD4U model mentioned in the theoretical framework [47], it can be concluded from the interviews that the analyzed university had digital resources and increased the quality and quantity of technological services. That is, the inclusion of specific technologies adopted by the university under study only partially describes the DT phenomenon, since a deep organizational change is clearly required. This change should be supported by the university managers in terms of leadership and strategy. In conclusion, it is worth mentioning that the main themes that emerged from this research work are related to the commitment to online training, the popularization of videoconferencing tools for teaching sessions, meetings or synchronous tutorials, and the acceleration of digital transformation, among others.

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education sciences

Article

Academic Self-Realization of Researchers in Higher Education: Phenomenological Research-Based Evidence

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Abstract: In the dynamic context of higher education, the academic self-realization of a researcher is significant not only for the growth of the dedicated researcher but also for the well-being of the entire academic community. The purpose of this study was to reveal the academic self-realization experience of researchers in higher education and answer the research question: "What does academic self-realization mean for the researcher in higher education?" This study used a phenomenological-hermeneutic approach, which allowed researchers to delve into the academic self-realization experience of researchers in higher education. The study was conducted from November 2022 to December 2023 and represents the social sciences and the science of education. Individuals who have obtained a PhD, work as lecturers and/or researchers in Lithuanian universities, participate in the training of doctoral students, and who obtained bachelor's, master's, or doctoral degrees in more than one field of science took part in this study. This means that these researchers represent scientific multidisciplinarity. The research participants were from Lithuania and the United Kingdom. A total sample of seventeen researchers participated in the study. This article presents results from semi-structured interviews with six researchers, where the theme of "academic self-realization" emerged. The study results showed that the academic self-realization of the researcher in higher education is a process through which the researcher finds, develops, and represents personal interests and talents in the university's academic community, thereby contributing to the personal, scientific, and academic development of this community. The conducted research reveals the complexity of the academic self-realization of researchers, which includes a significant integration of academic and personal components.

Keywords: academic community; academic self-realization; higher education; phenomenology; researcher

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1. Introduction

The desire for meaning inscribed in the human being permeates every area of a person's life. The search for meaning is in the areas of personal and academic life [1]. The abilities and talents of a person harnessed in the work arena ensure not only financial benefits, but also lead a person to meaningful self-realization. The term "self-realization", introduced by Carl G. Jung (1875–1961), was later adopted and deeply analyzed by representatives of humanistic psychology [2,3]. Self-realization is aimed at a person's self-actualization and includes a person's autonomy to act, their subjectively experienced and experienced freedom, self-efficacy, respect for the self and others, the realization of creative abilities, and self-development [4]. Self-realization on the academic path gives a person the opportunity to know her or his strengths and weaknesses in order to achieve academic growth and continuous learning, thanks to which personal meaning is experienced.

In recent years, the topic of self-realization at work has been given a lot of attention [5–8] in the analysis of research in the psychological sciences, but self-realization is no less important in the science of education. Educational research conducted on teachers' [9–11] and students' self-realization [12–14] testifies to the relevance of this topic, but the topic of the academic self-realization of researchers in higher education remains a poorly researched phenomenon.

In this article, the focus is on the academic self-realization of the researcher in higher education. In the literature, the notion of "academic self-realization" is used less frequently than the notion of "academic self-actualization". These notions are not the same. Self-realization means fulfillment by oneself of the possibilities of one's character or personality [15]. Self-actualization is defined as the tendency for someone to become actualized into their full potential. This tendency might be phrased as the desire to become more and more of what one is or to become everything that one is capable of becoming [16]. So, "academic self-realization" means stepping up and accepting responsibility. By owning their academic lives, researchers pave a path of freedom, enabling self-expression, autonomy, and success. It is about filtering and managing thoughts, strengthening self-confidence, and improving creativity [17].

A researcher working in higher education has a number of scientific, pedagogical, and administrative obligations in the course of fulfilling their academic duties [18]. Research conducted by a researcher, projects carried out, scientific articles, monographs, and other scientific texts written testify to the available expertise and competence. A researcher's quest to know her or himself and understand the field of research goes beyond the limits of measurable, evaluable, and obvious scientific academic achievements (e.g., the number of publications, winning projects, supervised student theses, reports, awards, etc.) [19]. A dynamic process of academic self-realization lies in the scientific activities of a researcher, during which authentic scientific growth is experienced [20–24], creating meaning based on academic values [25–29] and existing as members of the academic university community [25] and the national and international scientific community [30].

Researchers in this article are considered to be individuals who have a PhD, work at universities, and who devote themselves to doing research. Those who took part in this study have obtained a PhD, work as lecturers and/or researchers in Lithuanian universities, participate in the training of doctoral students, and have obtained bachelor's, master's, or doctoral degrees in more than one field of science.

In the dynamic context of modern higher education, more and more attention is paid to the performativity of researchers [31,32], which leads to increasing workloads [33,34]. Growing demands on researchers [35] and balancing between different roles [36] have become a challenge to the academic well-being of researchers [37]. Therefore, in this context, the academic self-realization of a researcher in higher education becomes a relevant and significant topic about which there is a lack of research. A researcher's academic self-realization in higher education is not only an individual researcher's aspiration to realize her or his personal potential but also a process that is related to institutional structures of higher education and academic standards [38]. A detailed analysis of scientific literature on an international scale revealed that the phenomenon of academic self-realization of a researcher as an autonomous concept is not analyzed in the social sciences, and it is not examined in education science. Therefore, phenomenological methodology was used.

As a result, phenomenological methodology was chosen for this study, which provides an opportunity to reveal and understand the personal perspective of researchers on academic self-realization in higher education experienced in their daily lives.

Phenomenological methodology allows for structured disclosure of human experience and description of what and how it was experienced [39]. A phenomenological approach to the academic self-realization of researchers reveals their academic experiences, which are meaningful to researchers in higher education [40]. The research question in this study was: "What does academic self-realization mean for a researcher in higher education?"

The aim of this study was to reveal the academic self-realization experiences of researchers in higher education. The findings presented in this paper are part of a PhD study which was completed between November 2022 and December 2023.

Analyzing the research data, it became clear that the academic self-realization of the researcher in higher education is a process through which the researcher discovers, nurtures, and expresses her or his individuality, personal interests, and talents in the academic community, thereby contributing to the personal, scientific, and academic growth of the researchers' university community and beyond.

2. Literature Review

Self-realization can be described as the complete realization of one's potential, as manifested in peak experiences that involve the full development of one's abilities and appreciation for life [41]. The concept of self-realization is actualized in the works of C. G. Jung, A. Maslow, and C. Rogers, and it provides basic concepts that help us to better understand the individual evolutionary path in different contexts.

"Self-realization" for Jung was about individuation as a tendency of the evolution of personality towards a coherent and integrated ensemble. Self-realization is a process based on the idea of accumulation and lifelong personality development, and Jung believed that even a very old person could have surprising and useful insights if she or he were willing to look deep inside [42]. According to Maslow [41], the person must be aware and have the will to become a fully actualized being, which means to experience self-realization. It refers to the desire for self-fulfillment, namely the tendency to become everything that someone is capable of becoming [2]. For Rogers [43], the tendency toward self-realization is the whole process through which the individual achieves her or his potential to become a fully functioning person. Rogers has associated the process of self-realization with the stimulation of functioning: self-realization with openness to a variety of experiences; participation in every moment in personal life by living to the fullest and experiencing life without preconceptions; and giving confidence to the individual's own body, to what she or he feels and perceives by trusting the freedom of decision and creativity.

In this article, the research focus is not on "self-realization" as a psychological concept. Attention is paid to "academic self-realization", which is associated with the researcher's academically engaged life in higher education, being part of the university's academic community. Therefore, it is worth touching on the meaning of the term "academic".

An academic is a member of a university or college who teaches or does research [44]. "Academic" means pertaining to areas of study that are not primarily vocational or applied, such as the humanities or pure mathematics; acquired by formal education, especially at a college or university; and conforming to set rules, standards, or traditions [45]. It also means relating to schools, colleges, or universities or connected with studying and thinking, not with practical skills: academic subjects/qualifications/books, an academic institution, or academic standards [46]. It could be summarized that dictionaries represent the semantic meaning of the notion of "academic" with a focus on institutions, teaching, researching, rules, standards, traditions, and formal education. This means that given a researcher's education and intellectual skills and their belonging to the academic community of the institution, compliance with rules and standards are important aspects. The literature review showed that the concept of "being an academic" is a limited approach and includes different contexts: institutional and disciplinary type [47,48], career stage [49,50], and gender [51].

When combining the concepts of "self-realization" and "academic" and constructing the complex concept of "academic self-realization", the scientific literature does not provide theories to explain such a notion. However, a review of scientific sources allows us to form a general picture of the concept of "academic self-realization".

Academic self-realization of a researcher in higher education is aimed at the self-actualization and self-expression of an individual, connected to the academic community of the university, and is experienced through self-building of scientific reputation in the academic community [20,22,23], multifaceted growth [24], the creation of meaning through scientific activity [25], personal self-expression in academic activities [52–54], continuous reflection of personal scientific path [55], presence in inclusive environments [56,57], authentic academic influence [58–60], intellectual freedom to create and think [61], intellectual contribution to science [62,63], personal growth in multidisciplinary environments [56,64,65], value integrity [26–28], and being a member of the university community [29].

The academic self-realization of a researcher in higher education is also associated with the self-creation of an academic reputation. A researcher's academic reputation is supported by formal and informal forms of communication [20]. When a researcher communicates with fellow researchers, students, and doctoral students, her or his scientific reputation is formed through scientific output, such as publications or conducted or ongoing scientific research [22]. Also, a scientific reputation is created when a researcher makes a personal contribution to the development [23] and cultivation of the academic community in higher education and beyond [21,52].

A researcher's academic self-realization in higher education means multidirectional growth in academic activities through which meaning is created. It is claimed that the multidirectional growth of a researcher manifests itself as a rhizomatic becoming, in which a personalized relationship with scientific activities is created [24]. The meaning created by a researcher during academic activities is perceived as a tension between pleasure (e.g., communication with students, teaching, financial well-being, being able to flexibly plan one's work schedule) and formalized burdens (e.g., bureaucracy, heavy workload, labor relations problems) [25].

A researcher's academic self-realization in higher education manifests itself in a person's self-expression through academic activities. Being a confident, recognizable, productive, and sophisticated researcher [53] provides an opportunity to express oneself as an authentic researcher and a unique personality in academic activities [54]. This self-expression takes place in the specific scientific and pedagogical activities of the researcher, which encourage continuous reflection on the personal scientific path. The received constructive feedback becomes the basis for reflection on the researcher's academic activities [55].

A researcher's academic self-realization in higher education takes place in inclusive environments and through authentic academic influence. Being in inclusive environments, the researcher develops her or his competencies [56] and shares her or his knowledge and experiences with other people [57]. A researcher's authentic academic influence is understood through the citation of scientific publications and the recognition of scientific expertise in the academic space [58,60] on a national or international scale.

The academic self-realization of a researcher in higher education requires intellectual freedom to create and think. Academic freedom and autonomy in higher education are understood as values [62] from which the researcher's intellectual freedom [38,66] arises and manifests itself when research is conducted and its results are shared with others [63]. Her or his intellectual contribution is created from the researcher's independent and authentic activity in higher education.

Intellectual freedom and academic freedom are related but distinct concepts. Intellectual freedom as an academic practice includes conditions that protect the freedom of access to information and ideas, no matter how controversial, so that scholars may freely teach and students may freely learn; the freedom to choose the spaces for research; the freedom to read; and the freedom of creative expression [67]. In accordance with Article 19 of the Universal Declaration of Human Rights, intellectual freedom is defined as encompassing the essential principles of freedom of thought, inquiry, and expression [68]; so then academic freedom can be defined as an application of intellectual freedom in the university setting [69].

Academic freedom means the atmosphere of free inquiry and discussion necessary to find and teach "truth" as the faculty member (researcher/scholar) sees it. It is the freedom to research any topic and to report one's findings without fear of retribution [70]. It is a freedom of inquiry in research, freedom of teaching within the university or college, and freedom of extra-mural utterance and action [71], the free exchange of ideas, and the development of an institutional culture that tolerates those who hold diverse views [69].

Academic freedom is usually guaranteed not on the basis of constitutional rights but rather as the result of contractual agreements.

The free exchange of ideas and the holding of diverse views might suggest a connection between academic freedom and freedom of speech [72]. Therefore, intellectual freedom and academic freedom share common roots, but they differ in some significant ways [69]. All persons are entitled to intellectual freedom, but researchers are entitled to academic freedom. Intellectual freedom does not presume the responsibility of competence, but academic freedom does. Intellectual freedom is not bound to any specific institution, like a university, but academic freedom is [73].

The intellectual freedom of the researcher manifests itself as a part of academic freedom, which opens up as autonomy, through which freedom of belief, expression, and debate are guaranteed [59]. Academic freedom ensures the researcher's freedom of speech, which is an essential element of intellectual freedom. A researcher working at a university is free to share her or his thoughts and insights during lectures, and while conducting research, he or she is free to share her or his research findings with other researchers, students, and the public.

Scientific creativity, which includes the characteristics of the researcher's personality, life events, academic experience, broad interest, and openness to the unexpected, helps to create an authentic intellectual contribution of the researcher's intellectual freedom, which provides meaning and contributes to the academic self-realization of the researcher in higher education [63].

A researcher's academic self-realization in higher education is reflected in multidisciplinary growth. This growth is related to the scientific discipline represented and employed [64,65], but in a multidisciplinary environment, one discipline is not enough to solve complex societal problems [56]. In a multidisciplinary environment, the researcher contributes with her or his insights and expertise to the creation of a cooperative academic relationship, in which expert experience and knowledge are shared.

A researcher's academic self-realization in higher education manifests itself through the researcher's value firmness. According to the researcher, the value strength is manifested in the relationship between the researcher and her or his research participants, where there is an educational interaction based on respect [26]. The value strength of a researcher is evidenced when scientific research is carried out responsibly and carefully [27]. The researcher's internalized values in the context of science are revealed when decisions about research and projects are made, when methodological choices are considered, and when research-based evidence is sufficient to support scientific claims [28]. A researcher's academic self-realization based on high morals and value firmness shows the individual's commitment and honesty to science and the entire higher-education community. Being a member of a specific university community is a context in which a researcher forms her or his academic identity and experiences academic self-realization [29] through research and pedagogical activities. Academic self-realization as a researcher involves a holistic process of achieving personal scientific potential and academic fulfillment. This process involves the building of a scientific reputation through formal and informal interactions within the academic community and a multidirectional growth characterized by rhizomatic becoming [74]. It is the construction of meaning in the tension between the joys and burdens of academic life [75]. This includes personal self-expression, constant reflection on the academic journey, and being present in environments that engage the researcher [76]. Researchers enjoy authentic academic impact, intellectual freedom, and interdisciplinary growth while maintaining a sense and meaning of institutional University Values [77]. In experiencing this, researchers contribute to the development and nurturing of science through their intellectual contribution to the university as academia. Being a part of the university's academic community provides opportunities for researchers to experience academic self-realization.

3. Methodology

3.1. Design

A qualitative research design was chosen to reveal what academic self-realization in higher education means for researchers. A qualitative research design allows for an in-depth exploration of participants' perspectives and lived experiences, which is particularly significant in capturing the richness and depth of their narratives [78]. A phenomenological qualitative research methodology was chosen because it enables the researchers to go deeper into the essence of lived experience and to see the structures within it. The main aim of phenomenology is to go beyond superficial interpretations, thus delving into the depth of consciousness itself. Unlike other qualitative methodologies, which may focus on generalization or theory building, phenomenological research aims to capture the unique and complex details of individual experience [79,80]. Phenomenology recognizes the importance of the role of the researcher, and reflexivity is therefore encouraged, which is crucial in the research process and interpretations. The process of phenomenological reduction allows the researcher to rethink her or his assumptions, beliefs, and personal experiences, which may influence the understanding of the phenomenon under study [81]. Through reduction, the researcher refrains from preconceived notions about the phenomenon under study, thus perceiving the phenomenon as it is. A qualitative phenomenological research design enables the researcher to understand the human experience holistically.

As a research methodology, phenomenology is uniquely positioned to help researchers in higher education learn from the experiences of colleague researchers. Phenomenological research is particularly effective at bringing to the fore the experiences and perceptions of researchers from their own perspectives and, therefore, at challenging structural or normative assumptions. Phenomenological research helps to understand what it is like for researchers to experience academic identity in higher education. By describing the stories of researchers who actually lived through a particular experience and their perceptions of it, our research cuts to the heart of what it was truly like.

In this study, academic self-realization was identified as one of the themes in the analysis of the research data based on Lindseth's and Norberg's [82] phenomenological-hermeneutical method for researching lived experiences. The application of the phenomenological-hermeneutic method to the study of lived experience is inspired by the theory of interpretation presented by Paul Ricoeur's (1913–2005) [83–85] interpretive framework for the analysis of interview texts. The stories told by research participants give meaning to specific events as well as to history as a whole [82,85]. Making the past events of the research participants present allows for a full understanding of their lived experiences and a new perspective on the lived world. The phenomenological methodology in this study was chosen because it allows the researchers to grasp the meaning that is embodied in the research participants themselves [86].

Phenomenological research helped the researchers to understand what it is like to experience a specific situation or life event in regard to the academic self-realization of a researcher in higher education. The stories of researchers who actually lived through a particular experience and their perceptions of it provided possibilities for researchers to grasp the essence of what it was truly like [37]. This method was meaningful in this study because there are not many theoretical justifications and empirical studies on the academic self-realization of researchers. If there are such studies, they are only fragmented, examining aspects related to "self-realization" but not the phenomenon of "academic self-realization" itself through the lived experiences of researchers. This article presents a part of the research on the academic identity of a researcher with a multidisciplinary education in higher education.

The study was conducted from November 2022 to December 2023 and represents the social sciences and the science of education.

3.2. Sample

Purposive sampling was used for the qualitative phenomenological study. Purposive sampling is a strategy used in qualitative research to identify and select research participants who have specific experience of the phenomenon of interest [87]. Similarly, in phenomenological research, purposive sampling has enabled the researcher to find research participants who share a common experience but have authentic characteristics and individual lived experiences [88]. The choice of purposive sampling led to the selection of the study participants according to criteria that defined that the study would include only university researchers with at least 10 years of work experience, as well as only university researchers who have changed their field of study (e.g., have studied in the natural sciences and the social sciences) at least once in their research and academic careers.

Convenience and snowball sampling were also used to facilitate the search for research participants. Convenience sampling is carried out by finding nearby, easily accessible study participants who meet the required criteria [89]. Convenience sampling allowed us to start the study from the proximate environment and then broaden the search for study participants through snowball sampling. Snowball sampling allows the researcher to reach potential study participants through those individuals already participating in the research [90]. These types of sampling in qualitative research enable the researcher to reach a wide range of research participants whose shared experiences added to and expanded the phenomenon under study.

Individuals who have obtained a PhD, work as lecturers and/or researchers in Lithuanian universities, participate in the training of doctoral students, and who have obtained bachelor's, master's, or doctoral degrees in more than one field of science took part in this study. This means that these researchers represent scientific multidisciplinarity. The research participants were from Lithuania and the United Kingdom, working at Lithuanian universities. A total sample of seventeen researchers participated in the study.

This article presents results from semi-structured interviews with six researchers. In these interviews, the theme of "academic self-realization" emerged. Characteristics of these six research participants are presented in Table 1.

Table 1. Demographic characteristics of the six research participants.

Research Participant	Gender	Work Experience	Represented Scientific Fields	Country of Origin
RP2	Male	24 years	Medicine and health sciences, medicine Social sciences, sociology	Lithuania
RP4	Male	24 years	Natural sciences, biology Social sciences, education	Lithuania
RP10	Female	28 years	Natural sciences, mathematics Humanities, philosophy	Lithuania
RP15	Male	25 years	Humanities, philosophy Social sciences, sociology	United Kingdom
RP16	Female	26 years	Social sciences, education Social sciences, political sciences	Lithuania
RP17	Male	30 years	Medicine and health sciences, nursing Social sciences, social work	United Kingdom

3.3. Data Collection

Semi-structured phenomenological interviews were conducted in this study. The semi-structured interview is a widely used technique in the social sciences in which research participants answer open-ended questions that have been pre-designed and prepared by the researcher [91]. A phenomenological-hermeneutic approach distinguishes the interview as a particular means of understanding the richness of a phenomenon and a way through which a conversation about the meanings of individuals' experiences is developed [92]. During the interviews, the researcher asked six questions to those who agreed to participate in the research:

1. What do you do at the university? Please share your experiences.
2. What does it mean to you to be a researcher?
3. It is said that academic-research activities are a kind of service. What do you think? Why? Please share your experiences.
4. Does academic freedom contribute to research identity? Why? Please share your experiences.
5. How and in what ways does your educational background contribute to your research identity? Please share your experiences.
6. How and in what ways has your academic career contributed to strengthening or weakening your academic identity? Please share your experiences.

In collecting research data, the researcher asks questions in order to obtain narratives of the lived experiences of the research participants [93,94]. For this reason, the participants were free to put into words their experiences that became significant in revealing the phenomenon under study. In order for the experiences and narratives of the research participants to be perceived without the researcher's biases, there is a significant phenomenological reduction, also known as bracketing, which allows the essence of the lived experience to be glimpsed [94].

The study respected the principle of impartiality. This was not an insider's research. The research participants were not colleagues in other studies or co-authors of other scientific publications. All participants were unknown to the researchers.

Each participant in the study was given the opportunity to freely choose the way in which they would meet for the interview. All but two of the researchers in the study expressed their willingness to be interviewed remotely. Suitable times and suitable university locations were arranged with the two female researchers who expressed a willingness to be interviewed in person, where it was possible to conduct the interviews freely. The duration of the interviews varied between a minimum of 43 min and a maximum of 65 min. All interviews were recorded and immediately transcribed, which means that before the next interview, the researcher was engaged in the transcription of the previous interview recordings. All interviews were transcribed manually, noting the emotions and pauses of the participants during the interviews. According to Tang [95], manual transcription is better because it ensures the utmost diligence and attention to detail in conveying conversations accurately, honoring individuals' truths, and generating reliable evidence from raw data.

3.4. Data Analysis

The aim of phenomenological research is to uncover, detail, and structure the lived experience of research participants [96]. In order to analyze and describe the research participants' experiences of their academic self-realization in higher education, Lindseth and Norberg's [82] phenomenological hermeneutic research approach was adopted. The data analysis phase consisted of four methodological steps [82]:

1. *Naïve reading.* The first step is familiarizing oneself with the interview text, so it is read several times in order to grasp the overall meaning. In order to grasp the overall meaning of the text, the researcher reads the transcript of the interview until she or he is open to what the participants have said about their lived experiences. In the process of naïve reading, the researcher has to let go of all preconceptions that would prevent the opening up of the personal life experiences as told by the participants. Naïve reading seeks to move the researcher from a naturalistic to a phenomenological perspective in the process of thinking about and looking at the text.
2. *Structural analysis.* For the researcher's structural analysis, the full text of the transcribed interview is broken down into units of meaning. A meaning unit can be a part of a sentence, a sentence, several sentences, a paragraph, or a text portion of any length in which the interviewee conveys only one meaning. In repeated readings, the meaning of each meaning unit is expressed as concisely as possible in everyday words. The similarities and differences between the extracted units of meaning are reflected upon during the rereading. For this reason, further grouping and, if necessary,

abstraction are carried out, thus formulating sub-themes and themes which are the essential meanings of the lived experiences of the participants.

3. *Comprehensive understanding.* At this stage, the main themes are summarized and reconsidered in light of the research questions, the research object, and the research context. The researcher then begins to search for literature on the essence of life experience that helps to revise, rethink, expand, and deepen the understanding of the text. The researcher does not adopt a literary perspective on the interview text but tries to see the interview text in the light of the literature and, conversely, to see literature in the light of the interview text. The researcher's entire attention is directed and focused on the lived experiences of the research participants in the lived world.
4. *Formulation of the research results in a phenomenological hermeneutic way.* The results are formulated in everyday language, as close as possible to life experience. This formulation of the results is based on the lived experience that individuals communicate to each other in everyday language. In narrative speech, certain poetic expressions or phrases emerge that reveal not only a mood but also possible ways of being in the world. For this reason, results can be revealed through poetic expressions, metaphors, or figures of speech.

3.5. Ethics

Institutional review board approval is required to ensure the safe, ethical, and standardized conduct of research with human subjects [97,98]. For this reason, the Ethics Committee of the Institute of Educational Research, Vytautas Magnus University, Academy of Education, was approached to review the study and grant permission for it to be conducted (27 September 2022, Protocol No. 15).

The research results presented in this article are part of a full-scale PhD study. Two researchers (the authors of this article) participated in the entire research process, whose roles were as follows:

- ☐ Researcher 1—conducting and systematizing the literature review; data collecting and transcribing qualitative data; presenting and interpreting empirical qualitative results.
- ☐ Researcher 2—structuring and abstracting the literature review data; supervising the analysis of empirical qualitative results; refining the interpretation of qualitative results.
- ☐ Both researchers—forming research design; selecting and refining the research methodology for the study; performing data analysis; refining the content and structure of phenomenological topics.

The ethical principles of respect for research participants, informed consent, confidentiality and anonymity, researcher integrity, and moral responsibility, which are characteristic of qualitative research [99–103], have been invoked in conducting the phenomenological research.

The relationship with the participants in this study was respectful, open, and cooperative. Researchers have a duty to respect informed consent in relation to research participants [104]. To ensure the ethics of the study, the principle of informed consent was followed, in which participants were given clear and understandable information about the study and the meaning of their voluntary consent to participate in the study. The researchers aimed to provide all the information about the study, its process, and data storage that was relevant to the research participants. Research participants were informed that they could withdraw from the study at any time and that such a decision would be respected and would not have any negative consequences in the future. The researchers gave the participants the opportunity to ask questions and receive clear and concrete answers. This principle ensured that the participants were completely free to take part in the research without any pressure.

Confidentiality and privacy have been respected in this study. Adherence to the principles of confidentiality and privacy ensures the privacy and identity of the participants in the study while also maintaining the integrity and credibility of the research process [104,105]. This ethical principle provided an environment in which research participants could freely share their personal experiences and opinions and feel safe. Confidentiality in qualitative research obliges the researchers to protect all research participants' information that could reveal their identity [103]. It was the responsibility of the researchers to ensure that all personal data of the research participants, including their names, other persons mentioned during the interviews, or other identifiable information, were not accessible to anyone outside the research. In order to maintain confidentiality, an abbreviation was devised for each study participant (e.g., Research Participant 4—RP4). During the interview process, the research participants' narratives were taken as their authentic lived experience, and the aim was to ensure maximum confidentiality and anonymity of the research participants.

The study followed the principle of beneficence to ensure the safety and welfare of the study participants [106]. In sharing their lived experiences, the participants also highlighted some sensitive moments that the researchers decided not to disclose in order not to harm the research participants. The aim was to ensure that the research carried out would not cause any harm to the research participants.

The study followed the principle of "fairness and honesty", which emphasizes the importance of transparency and ethical behavior during the research process, which is integral to maintaining the trustworthiness of qualitative research [102–105]. The researchers worked in an impartial, objective, and ethically based manner, which means that any possible manipulation or distortion of the study data was avoided. The two researchers were in constant discussion and consultation during each part of the process: data collection, analysis, and description of results.

In qualitative research, the trustworthiness of the study is a significant aspect. The trustworthiness of this study was ensured based on the following criteria:

The credibility criterion refers to the extent to which the results of a qualitative study are reliable and trustworthy [106]. To ensure credibility, each stage of the research, including interviews and their analysis, is described in detail. The results are presented in a coherent narrative form to illustrate the experiences of academic self-realization as lived by the researchers.

The dependability criterion implies that other researchers working under similar conditions can follow all the procedures and processes of the study [106]. To meet this criterion, every aspect of the research process was meticulously managed and documented. Comprehensive and detailed explanations are provided on how the research data were collected and analyzed.

The transferability criterion is related to the applicability of qualitative research results in different contexts and settings [107]. Although qualitative research is tied to a specific context, the insights presented in this study enhance the understanding of academic self-realization experiences among researchers. The results of this study are meaningful and beneficial to scholars working in higher education.

The confirmability criterion focuses on the objectivity and impartiality of the research results [106]. To avoid any potential bias, the researchers illustrated the findings with quotes from participants, confirming that the results were derived from direct data collected during the study. The results were prepared through ongoing discussions and reflections among the researchers on the participants' experiences. Such discussions and reflections ensured that the research findings were convincing and grounded in the lived world.

4. Findings

Analyzing the research data, it was determined that the researchers' academic self-realization in higher education is revealed through 13 subthemes (see Table 2).

Table 2. Subthemes within the theme of academic self-realization.

Subthemes	Theme
Self-creation of scientific reputation in the academic community	
Multidirectional growth at the university	
Making meaning through scientific work	
Personal self-expression through academic activities	
Continuous reflection on a personal scientific journey	
Being in inclusive environments	
Authentic academic influence	Academic self-realization
Intellectual freedom to create and think	
Intellectual contribution to science	

When a researcher begins her or his activity in higher education and aims to become established in the academic community, she or he comes to it with a certain research direction in which they have already accumulated a certain amount of experience. However, in order for such an establishment to be successful, it is significant to see the direction of one's interests and research integrally with the members of the academic community. Through this, a self-creation of scientific reputation in the academic community happens:

> *I did not experience any particular stress in my career as a researcher. I was so lucky to be able to do what I was interested in. No one restrained me. Only after falling into the formed team every time I was able to offer something to others, in order to do what I wanted. And if you want to work in a team, you have to convince people that it is also somewhat important to them. If you convince, then you can work, but you have to give something to those people who work around you.* (RP4)

This means that the researcher's academic self-realization is contextual. The ability to demonstrate the wider utility of one's interests and research areas in the scholarly community enables an individual to develop their academic career and successfully integrate into university activities. By being able to demonstrate the benefits of personal areas of interest to others, the researcher encourages the development of new potential research and establishes collaborative relationships that become multidirectional growth at the university. This dynamic growth in the university would not be possible without academic freedom and the actualized academic identity of the researcher. The question of meaning awakens the awareness of the researcher and the authenticity of the designated person:

> *People realize themselves differently. Sometimes the same people are active in both communities and schools. You discover each one differently, how that person sees himself meaningfully in the university and he chose to be here because he feels that this is where he belongs. This is how he realizes himself. To me, this is the best example of how that academic freedom can manifest itself. None of us are the same and we are all different when we work here and each of us contributes something* (RP16)

With her or his activities and personal contribution, the researcher promotes the progress of higher education and experiences academic self-realization after finding her or his niche in it. Scientific activity requires a lot of energy, time, and effort; the freedom to create and the opportunity to share it, influence, and bringing about constructive change gives inner satisfaction. The creative beginning and deep desire to know in the academic identity of a researcher becomes the meaning-making through scientific work. Empirical research, writing, and publishing are expressions of meaning through which a researcher experiences inner satisfaction:

> *When you stop doing what gives you meaning in life, that is social death. Then you find yourself in God's waiting room and begin your slow descent into biological death. So, I'm not sure if that will happen, but I still have a plan, which is more of the same research, writing books, writing articles, teaching. Autoethnography is becoming more and more mine and mine.* (RP15)

A researcher's constant involvement and presence in scientific activities are an integral part of life, which becomes a certain way of life. Involvement in scientific activities is not only the development of a personal career but also the creation of a personal meaning in life. Through this activity, the researcher utilizes her or his personal talents, abilities, and expertise, and by sharing this with the academic community or society, they bring about a change. The personal self-expression of a researcher through academic activities brings external success, but at the same time, it gives the researcher internal satisfaction and meaning. Being a researcher becomes a form of expression of a person but does not define them as a whole:

> *Deep down, it doesn't matter who we are—whether we are cooks, bakers, pilots or researchers, deep down, probably completely different things are important and they don't really have academic characteristics. Scientific activity is a form of expression of deep human reality. There is a very good medieval saying. I think it was formed in late Antiquity, but it became established as such a motto when talking about human expression and it sounds like this: Forma suponit natura. The form presupposes, provides as a premise, nature, essence, certain. I would like to consider this hierarchy as a starting point for the answer. Nature is the essence and then the forms of expression of a person working in the academic activity of a researcher, in this form I do not consider essential, essential. A researcher is not an essence, a researcher is an expression, a form. The essence is a number of other things and, well, what is expressed as the academic activity of a researcher or teaching academic activity in a academic activity, it is an external expression of that inner core.* (RP10)

That is why a researcher, as a person, is much more than just a representative of an academic profession. The academic identity of the researcher merges with the personal identity of the individual, thus helping to realize the nature of the person. Research activity becomes a way to realize the desire to know, discover, and create, which is inherent in the nature of each individual. Meanwhile, the academic identity of a researcher is supplemented by the unique experiences, values, and beliefs of the individual. This means that the integrity of the researcher as a person and the researcher as a representative of the academic profession gives research activities a personal tone, from which comes a continuous reflection on a personal scientific journey:

> *I have a friend of mine, a classmate who was a famous runner. I only understood this from him, he explained it to me. I thought he was competing with others, he explained to me, that is not the case, that in reality every runner is only competing with himself. It is similar in science too, probably. Doing something like that, doing something you like, solving your own puzzles or those invented by others, if you like such things, if you don't, it's not for you. But here, too, it is too much to look for the answer "for you or not for you", it doesn't take long, you will soon understand. It's like skydiving. You know how they say that if the first jump didn't work, it's not for you.* (RP4)

Reflecting on her or his experience, this researcher realizes that it is not always and not in all cases important to strive for what is externally considered success, but after discovering her or his personal potential, she or he should start realizing it. During the researcher's personal self-reflection, it is important to set personal expectations and standards that promote inner growth and development. By paying attention to the reflection of personal experiences, the researcher becomes primarily transparent to her or himself. When a researcher realizes that it is not the compliance with surrounding expectations or external success indicators that is most significant but the improvement and cultivation of oneself as an expert in a specific field, then the researcher becomes a creator of personal success and value, thus realizing her or himself in higher education.

The activity of a researcher is not isolated from other persons working at the university. Through interaction processes, it becomes clear with whom one cooperates and works together, whose values coincide, and who cultivates and encourages one to become a better specialist in one's field. For this reason, the academic socialization of the research community encourages *being in inclusive environments* where intellectual sharing and academic growth can take place. Reflecting on the experience, the research participant highlighted that "being a researcher is an opportunity to find yourself in environments that are interesting to you, they involve you. This is such a huge opportunity. It's very possible to actually be in environments where you can draw on that knowledge. And then it's a big responsibility to spread it to others" (RP2).

Participation in scientific conferences and expert groups or being a member of scientific clusters gives a researcher the opportunity to share her or his accumulated scientific and research experience, as well as to learn from them in interaction with colleagues. In this way, the researcher constantly updates her or his and others' scientific knowledge and understanding. In these different interactions, authentic academic influence is exerted, from which two-way benefits arise—for both the researcher and the academic community:

> *Now it is difficult to imagine some individual researchers, but there are some, and they may require special attention and respect, but this is their own choice. If you want to work in a team, in such an academic world per se, don't be a hermit–a weirdo, but look at what is interesting to everyone together. But first you need to look at what is interesting to you. I did not experience any contradictions around. And that was the most important thing for me. I guess it should be said that the most important thing for me was to do what I like to do. And the more influence you have, the better.* (RP4)

Having the opportunity to exert a scientific influence, a researcher thinks not only about the common good—the growth of the academic community—but also about the development and expansion of her or his own field of interest. The influence of a researcher in a university gives an opportunity to experience satisfaction with one's activities and to realize even more deeply one's commitment to higher education. A researcher's self-realization through scientific influence provides an opportunity to create a long-term legacy of her or his scientific work, which testifies to the directionality of a person's activity and its purposeful fulfillment.

A researcher's self-realization in higher education is based on intellectual freedom to create and think, where a researcher can choose immersion in the world of ideas and live in it without external stimuli or other possible pressures:

> *There is much more freedom in the world of ideas than in the real world. If you are able to immerse yourself in what is a significant part of your work, then you will spend a lot of time in a world where you have a lot of freedom and much more freedom than in the everyday world. It's nice and you get paid for it. Who wouldn't want that . . ..* (RP4)

Being in the world of ideas is an opportunity not to restrict yourself and to freely search for new, creative approaches, which can later become real empirical research. In the world of ideas, a researcher is not limited by traditional approaches or dominant higher-education fashions, which censor the researcher's creative pursuits in a peculiar way. Immersed in this activity, a researcher experiences a deep sense of self-realization, thanks to which a person's academic identity and dedication to their activity are strengthened. The experienced intellectual freedom gives the researcher the opportunity to develop her or his scientific and creative potential, thus bringing an intellectual contribution to the science. A researcher's intellectual contribution is not just mechanical work in which a person "bakes" publications, monographs, or other academic texts, but it is a specific researcher's personalized relationship with the researched topic. The experienced joy of knowledge and the realization that one's specific work contributes to the creation of new scientific knowledge give meaning to the activity of a researcher:

> *I loved books and reading and libraries. All those considerations of Jorge Luis Borges about the world as a library, or about the library as a world, are very interesting to me. They are very understandable and close to me. I loved books, I loved the process of reading and learning. It's the same with science: that you not only like what you do, but you also start to like the daily academic routine. You came to the library, it smells like something . . . the smell of book dust. And then you have to write the thesis and at some point you*

> *start to understand that maybe here you too contribute to the academic world and are a person of letters. Even if it's a small piece of work, maybe it's graceful enough and maybe you've solved some kind of problem that no one else has not yet resolved. At some point, you feel that academic work is a pleasant process itself. Then everything happens by itself.* (RP4)

The achieved result is important in the activity of a researcher, but the research process, in which a person experiences that they are not only a researcher but also a creator, is no less significant. A researcher's intellectual contribution can sometimes be small, but at the same time, it can have a valuable meaning in the world of science, representing a new approach or an approach that has not been explored before. A researcher accepts possible challenges or difficulties in her or his activities, but realizing their commitment to higher education, she or he does not stop striving for quality in the entire process of *scientific creativity.* Research has been carried out, whether the created scientific works are final products that crown the work of a person or not. The desire to know that is embedded in the researcher's academic identity becomes a living and developing search process in which "the greatest thing is creativity and the joy you experience while creating. You look for something, you don't find it for a long time, then you find it, you come up with something; if you don't find it, then you spit and look elsewhere" (RP4). Experienced creative joy encourages the researcher to be in the position of a questioner and not stop searching. The researcher's potential, awakened in the process of scientific creation, becomes an opportunity for personal self-realization and growth of academic identity, in which learning and improvement do not stop.

Personal growth through multidisciplinarity directs researchers not to close themselves only in the monadic direction of science but to look at studied phenomena from different perspectives. In the process of becoming a researcher, a significant place can be occupied by the available education in different fields, which opens up the possibility of seeing research within the boundaries of more than one discipline:

> *Upon entering the university, there was a system in place, according to which each degree was divided into two parts–the first and the second. I had a friend from school who was a couple of years older than me and he went there. He was a classics major, studying Latin and Greek before switching to a second major in social and political science. In those days, the university did not have the first part of social and political sciences, usually people who graduated from economics decided that they did not want economics, so they chose social and political sciences. And I thought that was great. I can go and study science for the first part and then switch to social and political science, which I did and had a dual experience.* (RP17)

When a researcher gets to know different disciplines, she or he becomes more open to the diversity of viewpoints and the possibility of conducting research in an integral manner. Solving complex problems with the help of approaches from different disciplines allows a researcher to act multidirectionally and expand the possibilities of self-realization. By managing different methodologies and being able to see their integrity, a researcher finds creative approaches to solving emerging problems. Although the academic identity of a researcher is cultivated and developed through the study of different disciplines, one discipline can be essential and leading in the identity of a person because it is more responsive to interpersonal attitudes, talents, or personal interests:

> *In science, I realized that my peers were much better naturalists than I was. There were very great mathematicians. I wasn't really a mathematician. I knew that. I was quite interested in physics, but it wasn't that compelling. I was a bit interested in psychology. I did some other things. But when I got into the social sciences, I thought it was amazing. Then I got a scholarship to study PhD in sociology. I went to an economics school, defended my doctoral thesis there, and then started teaching at sociology faculties. So I always had this foundation.* (RP17)

This means that a researcher, despite having a wide education, can consider one discipline the main one and others as complementary and auxiliary in the course of scientific research. On the other hand, the ability to understand and manage multiple disciplinary fields enables a researcher to engage in a more constructive dialogue with colleagues from other fields within the academic community, thereby creating opportunities for broader collaboration that fosters mutual growth.

In the activity of a researcher, the strength of a researcher's values remains important and determines life choices and the forms by which academic identity is formed. The value strength of a researcher underpins a person's loyalty to their dignified academic choices and the ethical pursuit of personal goals in higher education or outside of it:

> *I remember it was 1994, maybe I only noticed then that it was the year when the academic world in Lithuania lost many active people. Such active, curious people who want to do something. Not necessarily all of them would have become very important researchers, but those people went into completely different fields. They went into some sort of fledgling business at the time, because the academic world was unattractive in material terms. I used to see my older colleagues there, with their jackets in tatters, waiting in line at the place where they had to pay their salaries. The salaries of academic people at that time were so very ridiculously low and I looked at them and thought that their lives had changed from the point where an associate professor's or a professor's salary seemed quite decent, and now they have become very low. I thought that's how society views those people, but that doesn't mean they're any less happy because of it.* (RP4)

A researcher who chooses to stay at the university even in the face of various challenges may appear strange and, in some sense, inadequate from the outside, but the intrinsic value firmness encourages the person to work and create in the chosen academic activity. A researcher's personalized desire to work and act in higher education helps them find ways and opportunities to overcome emerging challenges. Being a part of the university community gives a researcher internal motivation to stay in higher education and make efforts to change difficult situations through cooperation. On her or his academic path, a researcher chooses the academic community that is close in value: "I defended my doctorate at another university, I can compare that, and I worked at that university for a while. Yes, it seems to me that I would not voluntarily change to any other Lithuanian university. And I hope that we will maintain that identity as a community" (RP16). The value strength and purposeful action of the university community give the researcher the courage to make unpopular decisions that strengthen the person's authentic academic path and lead to full self-realization.

5. Discussion

Research results reveal that the researchers' academic self-realization in higher education is related to the self-creation of a scientific reputation in the academic community, multidirectional growth at a university, making meaning through scientific work, personal self-expression through academic activities, continuous reflection on a personal scientific journey, being in an inclusive environment, authentic academic influence, intellectual freedom to create and think, and intellectual contributions to science.

A researcher's academic self-realization in higher education is related to the creation of a scientific reputation. These results complement and extend Bourne and Barbour's [23] ideas that in building an academic reputation, a researcher must demonstrate the meaning of her or his research to other fellow researchers. The benefit of the personal interests shown by the researcher to the academic community becomes not only a successful establishment at the university but also academic self-realization.

Academic self-realization occurs when the researcher makes a personal contribution to the development and nurturing of the academic community, in higher education and beyond. The results coincide with the research findings of Mateus and Acosta [21] and Remich et al. [52], which show that academic self-realization takes place through the creation and development of a scientific reputation within and outside the academic community. Academic self-development is achieved through the reputation that a researcher builds by contributing to the development and expansion of higher education.

Academic self-realization is experienced through multidirectional growth in the university, which requires academic freedom. Multidirectional growth of a researcher at the university can be perceived as a rhizome, but without the academic freedom experienced, this growth would not happen [24]. Academic freedom gives a researcher's activity direction and purposefulness, which leads to a sense of meaning in academic activities. Irigaray et al. [25] agree that the meaning created by a researcher in higher education is perceived as a tension between pleasure and a formalized burden, and the scientific activity itself becomes a way of life for the researcher through which a person experiences academic self-realization. Then, the researcher's involvement and presence in the process of scientific writing becomes a pleasurable and meaningful activity.

A person's self-expression through academic activities is related to academic self-realization, but the main aspiration of a person is not to be a confident, recognizable, productive, and sophisticated researcher [53]. Being a researcher is only a form through which a person expresses her or himself and experiences the authenticity of her or his personality. This shows that a distinction is made between the person and the profession of a researcher. Experienced academic self-realization through scientific and pedagogical activities is rather a way in which a person experiences her or his own self-realization as a personality.

The academic self-realization of a researcher requires reflection on her or his personal path. The researcher's personal reflection is related to the processes of academic growth and development, which lead to academic self-realization in higher education. The present study is in agreement with the Pedrosa-de-Jesus et al. [55] research results showing that a researcher's personal self-reflection actualizes a person's internal aspirations and desires, which promote internal growth and development. In the researcher's journey of inner growth and development through personal self-reflection, growing self-confidence is experienced, which leads to academic self-realization. The academic self-realization of the researcher takes place in inclusive environments where authentic scientific influence is exerted. The results of this study match the results of Staley et al. [57], a study that examines how, in the presence of inclusive, interesting environments for the researcher, the intellectual exchange of the scientific community takes place. The results of the conducted study extend the ideas of Soheili et al. [58] and Kong et al. [60] by showing that although the citation or quotation of scientific publications and the recognition of scientific expertise are important in higher education, the pursuit of the common good is equally significant, creating a personal contribution to the academic community. Making an authentic impact in higher education on a national or international scale allows the researcher to experience academic self-realization.

A researcher's academic self-realization and intellectual freedom are related. The conducted study expands the Žydžiūnaitė [38] study results, which state that intellectual freedom is close to being a researcher in the world of ideas, where a person is not limited by traditional approaches or certain rules. A researcher experiencing intellectual freedom is free to create and share it with the academic community. The results of the study showed that the scholar's intellectual contribution is part of her or his academic self-realization. It coincides with the research results of Žydžiūnaitė [66] and Ruan [61], showing that a researcher with the freedom and ability to create authentically makes her or his intellectual contribution to the context of higher education through research and the dissemination of the results of their research. Such results and confirmations allow us to formulate the statement that a researcher's academic self-realization is experienced when she or he can create added value in the national or international higher-education communities by performing their direct duties.

The academic self-realization of a researcher is related to personal growth in multidisciplinarity. The results of the study fit with the study results of Karlsson et al. [56], revealing that working as a researcher in multidisciplinary environments encourages the establishment of collaborative relationships where intellectual exchange takes place in solving complex issues. This shows that a researcher experiences academic self-realization in higher education by being able to share her or his expertise in a multidisciplinary collaborative relationship, learn from other researchers, and expand the boundaries of her or his perception.

The researcher's value strength and being a member of the university community is related to her or his academic self-realization in higher education. The results of the study extend the ideas of Sirris [26] and Douglas [28] by highlighting that the researcher's values and high moral standards are important in conducting research. Value firmness can be manifested in the face of challenges when balancing career choices and considering other options in higher education. The choice to stay and work in higher education shows the importance of academic work for a researcher, through which academic and personal self-realization is experienced. Being a member of the university community strengthens the academic identity of a researcher, thanks to which a person experiences academic self-realization [25].

The study had two limitations: 1. The conceptual exploration of academic self-realization presented in this paper represents a preliminary effort. There is considerable reliance on the term "self-actualization" within the literature review. However, empirical research indicates a significant gap in academic literature and empirical studies specifically addressing academic self-realization. Consequently, the literature review is somewhat constrained and primarily descriptive regarding the related concept of researchers' academic self-realization. This underscores the necessity for further research in this area. 2. The study's justification of academic self-realization among researchers based on their selection in different disciplines at various levels of study is intentional. As one of the pioneering studies emphasizing the significance of multidisciplinary education, this can be viewed as a strength due to its innovative approach. Nevertheless, it also represents a weakness, as the paucity of scientific sources poses challenges in substantiating the presented ideas.

6. Conclusions

A researcher's academic self-realization in the dynamic context of higher education is significant not only for the individual researcher but also for the entire academic community. This study aimed to reveal the academic self-realization experience of researchers in higher education. A researcher's academic self-realization in higher education is a way in which a researcher expresses her or his uniqueness, personal interests, and talents by contributing to personal, scientific, and community growth in an academic environment.

The conducted phenomenological study complements and expands the concepts of academic self-realization of a researcher in higher education. The study reveals that multidirectional growth of a researcher at the university is possible when academic freedom for scientific creativity is ensured. A personalized relationship with scientific activity becomes a unique way of life through which a researcher experiences academic self-realization and, at the same time, the fulfillment and realization of her or his personality. A researcher's empirical research and pedagogical work in higher education are inseparable from their personal contribution to the common good. Being a co-creator of the common good is akin to a researcher's personal meaning, thanks to which academic self-realization is experienced. This study reveals the complex process of a researcher's academic self-realization in higher education, in which the integrity of academic and personal components is distinguished.

The results of this study reveal not only the importance of the academic self-realization of researchers but also the need to continue research on this topic. Further empirical research can be carried out by distinguishing the links between academic freedom and the creativity of researchers in the process of academic self-realization. Also, further research can examine the links between the academic self-realization of researchers and their working conditions, thereby promoting more sustainable functioning of universities and the well-being of academic communities of researchers.

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Article

Upward Bound Program Supports Success of Low-Income and/or First-Generation College Students at a STEM-Focused HSI

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Abstract: A deeper understanding of low-income and first-generation college student experiences is essential to advancing diversity and equity in higher education. Due to a significant gap in college enrollment and graduation rates for low-income and first-generation college students, specifically after COVID-19, it is important to identify factors affecting their success. The Upward Bound Math and Science (UBMS) Program at New Mexico Tech (NMT) supports high school students who are either first-generation college students and/or from low-income families to prepare them with the skills and motivation necessary to complete high school and enter and succeed in a program of postsecondary education. These students face unique challenges during their time at college. To identify the factors that affect the success of these students, we surveyed several of our UBMS program participants who chose to attend NMT after completing high school. All participants said support from UBMS staff was critical when starting college at NMT. Participants also mention building a support system with their fellow UBMS alumni to deal with the struggles that being at STEM-focused institutions brings. This study also resulted in several suggestions for faculty and staff members to improve academic outcomes for all students.

Keywords: support system; college adjustments; first-generation students; low-income students; college choice; college success; STEM-focused HSI

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1. Introduction

The Upward Bound Math and Science (UBMS) Program is a US Department of Education grant-funded program to support high school students who are either first-generation college students and/or from low-income families [1]. New Mexico Tech (NMT) has continuous funding through two grants to support the UBMS Program. The goal of the NMT UBMS Program is to prepare program participants with the skills and motivation necessary to complete high school and succeed in a program of postsecondary education. The project features activities such as daily courses taught by a licensed teacher at the school, or afterschool tutoring, financial aid workshops, college entrance admissions, and testing preparation, college campus visits, and a six-week summer residential program including a bridge (for seniors or graduates) and the internship programs held on the main campus of New Mexico Tech (NMT), Socorro, NM or University of New Mexico, Albuquerque, NM.

New Mexico Tech (NMT or Tech) is a Hispanic Serving Institute (HSI) and a STEM-research-focused university that spent over $89 million on research last year. This is significant due to the small size of NMT with only 146 full-time faculty members and 1169 full-time degree-seeking undergraduate students enrolled (NMT IPEDS data 2022–2023 [2]). Unfortunately, the 6-year graduation rate from 2018 (pre-pandemic) to 2023 ranges between 50–56%. This warrants an urgent change in the academic approach. The institution is predominantly male with only 31% degree-seeking female undergrads (NMT IPEDS data 2022–2023 [2]). NMT is rural, and the surrounding public school district is supported by federal Title I funding due to a high number of low-income students [3].

The US Department of Education defines a "low-income individual" as an individual whose family's taxable income for the preceding year did not exceed 150 percent of the poverty level amount. More specifically, in 2024, a student from a family of four whose taxable annual income was less than $46,800 will be categorized as low-income [4]. According to the National Student Clearinghouse Research Center 2021 report, only 79 percent of low-income students returned for the second year of college compared to 88 percent from higher-income high schools. Moreover, the six-year completion rate for students from high-poverty high schools is only 24 percent compared to students from low-poverty schools with a completion rate of 60 percent [5].

According to data from the National Center for Education Statistics (NCES), New Mexico ranks eighth in the states with the most first-generation college students. The US Department of Education defines first-generation students as individuals having no parent with a bachelor's degree. The percentage of first-generation college students is 42.8%. However, the enrollment for this cohort is not growing across the US. Some states have seen a decrease in enrollment between 2016 and 2018, and enrollment fell −14.85% in New Mexico [6]. This adds to a persistent issue that first-generation college students are less likely to apply to and attend college. Moreover, first-generation college students face more challenges at research universities as identified by Stebleton and Soria [7].

Going from high school to college is challenging for students and for making adjustments in one's life. Hazard and Carter (2018) believe there are six adjustment areas that first-year college students experience: academic, cultural, emotional, financial, intellectual, and social. Academic adjustment means that a student will be faced with the increased demands of learning [8,9]. This could mean that a student may need to adjust how to learn and take the time to understand their own learning styles to meet the demands of coursework. Cultural adjustment means that students may experience more diversity on campus and must learn or adapt to "college language", for example, "syllabus, registrar, advisor, and office hour". Another adjustment that students may experience is emotional. There is a range of emotions that first-year students may encounter at the beginning and during a semester or over the course of a year. A financial adjustment can also be experienced, especially for low-income first-generation students who need financial aid to continue with their studies. Having to think of how to pay for college can be very stressful. Students will have the opportunity to join others intellectually when on campus and in study groups, which can lead to new relationships allowing for social adjustments.

As indicated by several studies, a deeper understanding of first-generation college students' experiences is undoubtedly essential to advancing diversity and equity in higher education [10]. When applied to first-generation college students, the premise of Social and Cultural Capital Theories is that because the parents of first-generation college students did not go to college, the families tend to be of lower socioeconomic status, and the students are unprepared for college and/or are "lacking" the support and resources that are needed for a successful college career [11,12]. However, cultural capital can be acquired through formal education. Education was noted as the most powerful mechanism for achieving upward socioeconomic status [13]. Knowledge intentionally learned at school and the acquisition of degrees would represent cultural capital acquired educationally. Thus, first-generation/low-income college students can gain social status by attending college and completing a degree. Other theoretical perspectives included family support [10]. Roksa and Kinsley [14] refined the previous theories and argued that those students who get involved with the college community and have more family support will have stronger commitments to their educational goals. These strong commitments would, in turn, increase students' wanting to complete their degrees.

Historically, postsecondary education experiences have been limited due to barriers that some students face. These barriers include being the first to go to college, college readiness, financial challenges, racial disparity, lack of self-esteem, and college adjustment [15]. Due to these barriers, there is a huge gap in graduation rates for students with two parents with at least a bachelor's degree with a graduation rate of 82% to 20% for students with no parent with college experience (according to PEW research analysis of 2019 survey [16]). It is critical to identify these barriers to improve the graduation rates for low-income and/or first-generation college students.

In order to help identify these barriers, we surveyed participants as several of our UBMS program participants chose to attend NMT after completing high school. We invited current NMT students who participated in UBMS to interview with us about their experiences and how they overcame the limitations of being low-income and/or first-generation college students at a STEM-focused HSI, i.e., NMT. Self-efficacy questions were asked about their overall support of entering college, and their feelings about the coursework for three general education areas including English, Mathematics, and Basic Laboratory Sciences during their first couple of years at NMT. Other questions included support received for successfully transitioning through all six adjustment areas: academic, cultural, emotional, financial, intellectual, and social. Our two main research questions (RQ) are (1) What are the barriers faced by low-income and/or first-generation students at a STEM-focused HSI and how are they being supported? and (2) What are some of the ways to improve the graduation rates of all students?

2. Materials and Methods

2.1. Research Context

New Mexico Tech (NMT) has continuous funding through two US Department of Education grants to support the Upward Bound Math and Science (UBMS) Program. The first grant supports up to 55 students per year from Manzano and West Mesa High School in Albuquerque (located 75 miles from NMT). The second UBMS grant serves up to 61 participants from Socorro High School in Socorro, NM (same town as NMT). All three high schools demonstrate high need and have a large population of eligible students (low-income and/or potential first-generation college students). Some of these UBMS participants chose to attend NMT after high school graduation.

2.2. Purpose of the Study

This study aims to identify factors affecting the success of low-income and/ or first-generation college students at a STEM-focused Hispanic Serving Institution (HSI)—specifically, at NMT. Graduation rates for low-income and/or first-generation college students have significantly dropped after COVID-19. Two Department of Education TRIO grants fund the Upward Bound Math and Science (UBMS) program at NMT. The UBMS program aims to increase the rate at which low-income and/or potential first-generation students complete high school and enroll in colleges or universities. For the UBMS grant's annual progress reports, we collected data for the number of high school graduates who attend colleges or universities the following academic year. We tracked new college enrollees using the National Student Clearinghouse [17] for the next six years and report their college attendance or graduation status. For example, students who graduated from high school in 2012 were tracked until 2017–2018. Based on tracking information between 2012–2014, we had 33 high school graduates who attended any post-secondary institutions within the next academic year. Their six-year timeline culminates between 2017–2020, and we refer to this as the pre-COVID-19 bachelor's degree completion rate in Figure 1. Pre-COVID-19, out of 33 students who enrolled at a college/university, only 15 (45%) completed a bachelor's degree. As depicted in Figure 1, post-COVID-19 bachelor's degree completion rate dropped to 31%. Between 2015–2017, 35 high school graduates started college the following academic year and only 11 (31%) graduated with a bachelor's degree within the next six years. These results suggest college students from low-income and/or first-generation families (UBMS participants) were significantly impacted by COVID-19-related disruptions.

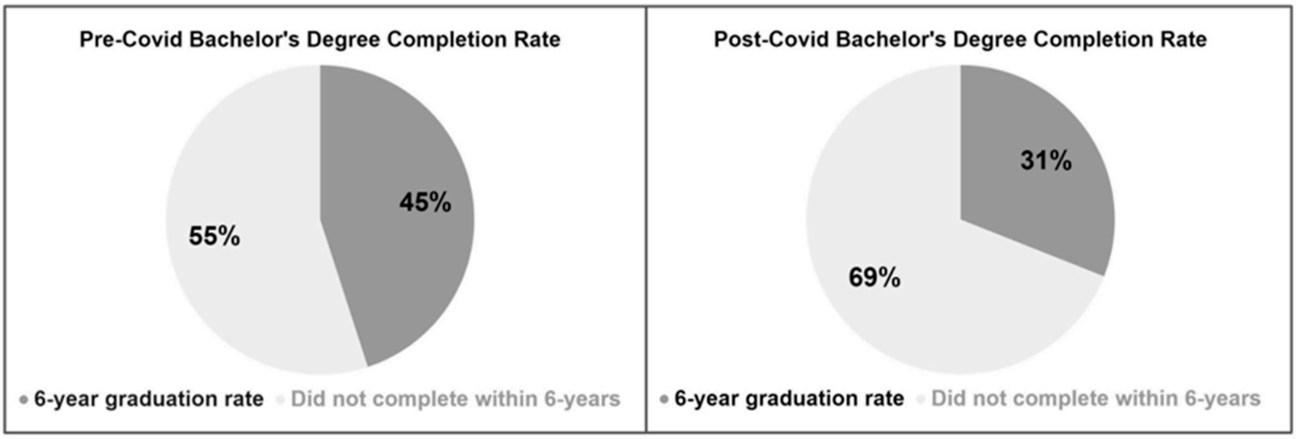

Figure 1. Six-year graduation rates for first-generation and/or students from low-income families who participated in the Upward Bound Math and Science (UBMS) program during their high school years. Pre-COVID-19 graduation rates for students entering college between 2012–2014 who would graduate between 2018–2020, respectively. Post-COVID-19 graduation rates for the 2015–2017 cohort who would graduate between 2021–2023.

2.3. Participant Selection

Our UBMS program serves students from Socorro High School, as well as Manzano, and West Mesa High Schools. After high school completion, several UBMS students pursued a higher education at NMT and the grant project employs some of them. We contacted all current NMT students who participated in the UBMS program and invited them to interview with us in person. Only eight currently enrolled NMT students and past UBMS participants responded and agreed to interview with us.

2.4. Interview Process

The individual interviews were conducted in person and in an office setting in the Fall 2023 semester. The interviews started with the IRB disclaimer and permission was taken to record. The responses to the questions were audio recorded and simultaneously noted using Google Doc voice typing. Some interview questions were adopted from [18].

2.5. Data Analysis

The data was analyzed through MAXQDA24 (VERBI Software, Version 24). This software is designed for qualitative and mixed-method data analysis. MAXQDA24 assisted us with our data analysis by organizing the eight participants' answer documents and recorded interviews to easily access the needed information. Some of these summary data sets were transferred to Excel to produce graphs or tables to further aid our investigation. Author B.H. did the initial data analysis. Authors T.A. and M.K. independently validated the data. The authors met and discussed to reach a consensus in describing the final results. Each question was individually analyzed and the results are presented accordingly.

2.6. Comments from the Participants

All direct comments from the participants are italicized. Personally identifiable information was removed. To further help keep the identities of the participants private and to help with the organization of the paper, pseudonyms were used to identify the eight participants. The text was corrected for grammatical errors and edited (summarized or provided contextual information) to improve readability.

2.7. Positionality Statement

We intend to be transparent by stating our positions and acknowledging that the authors' backgrounds and experiences may have impacted some of the data interpretations in this study.

Author B.H. is a student at New Mexico Tech (NMT) working towards a Bachelor of Science in biology and a minor in secondary education. B.H. was introduced to NMT by her high school chemistry teacher in Bloomfield, New Mexico who is an alumnus of NMT. Yet, in her first semester, she was the only student from her high school's graduating class to attend. Her hometown is approximately 4 hours' drive from Socorro, which proved to be challenging due to the far distance away from family and friends. In her immediate family, she will be the first to graduate college. These factors proved challenges in navigating her college experience, but nonetheless, she will graduate successfully. Her experience as a first-generation college student at a STEM-focused Hispanic serving institution may have consciously or subconsciously shaped some of the data analysis and interpretation in this study.

Author T.A. is a professional educator with 29 years of teaching experience. Since she was in second grade, she dreamed of becoming a teacher. However, her start to obtaining a higher education was not easy. Along with being Hispanic, she grew up in a low-income household with no guidance on continuing education after high school. Out of a family of six, only her mother, one of her three brothers, and her graduated from high school. Fortunately, a few years after high school, she met a cohort of friends who were in college and they guided her in applying for college, registering for courses, and seeking financial aid. It is there she learned that despite not having money, she could still attend college and make her dream of becoming a teacher a reality. Against all odds, she became the first in her family to attend college and eventually completed three higher education degrees. After teaching middle school for over two decades, she accepted a position to become an Instructor of Education at NMT in 2020. Because of her struggles as a low-income and first-generation college student, she understands that these students require additional support, and they need to be shown that help is available to succeed.

Author M.K. is an immigrant and a first-generation graduate student in the US. She completed her PhD in Chemistry at a land-grant Hispanic serving institution in 2013. Afterward, she worked as a high school science teacher. She has been supervising Teacher Education Programs at NMT since 2017. In Fall 2023, she accepted the position of Assistant Professor of Chemistry Education at NMT. Throughout her career, she has worked with underrepresented and underserved students including low-income and potential first-generation college students. To improve educational outcomes for this student population, M.K. submitted and received funding from the US Department of Education for NMT's two Upward Bound Math and Science grants in 2022. She would like to acknowledge that her struggles with a new education system and being so far away from family as well as her work experience at NMT may affect the data interpretation for this study.

3. Results

3.1. Common Themes Identified

Participants' answers to questions fell under one or several of the adjustments previously mentioned by Hazard and Carter (2018): cultural, academic, emotional, financial, intellectual, and social. These adjustments were identified as common themes to better understand how the students were doing.

3.2. Background Information for Participants

Eight current New Mexico Tech (NMT) students participated in our interviews. As shown in Figure 2, all eight students participated in the Upward Bound Math and Science (UBMS) program and identified themselves as Hispanics when asked, "What is your primary race/ethnicity or choose not to answer?" Six out of eight participants were first-generation college students. We did not ask if they were from low-income families because, to be a part of the UBMS program, they are potential first-generation college students and/or from low-income families. Interestingly, six out of eight students identified themselves as female even though NMT female students make up only 31% undergraduate population according to IEPDS data from 2022–2023.

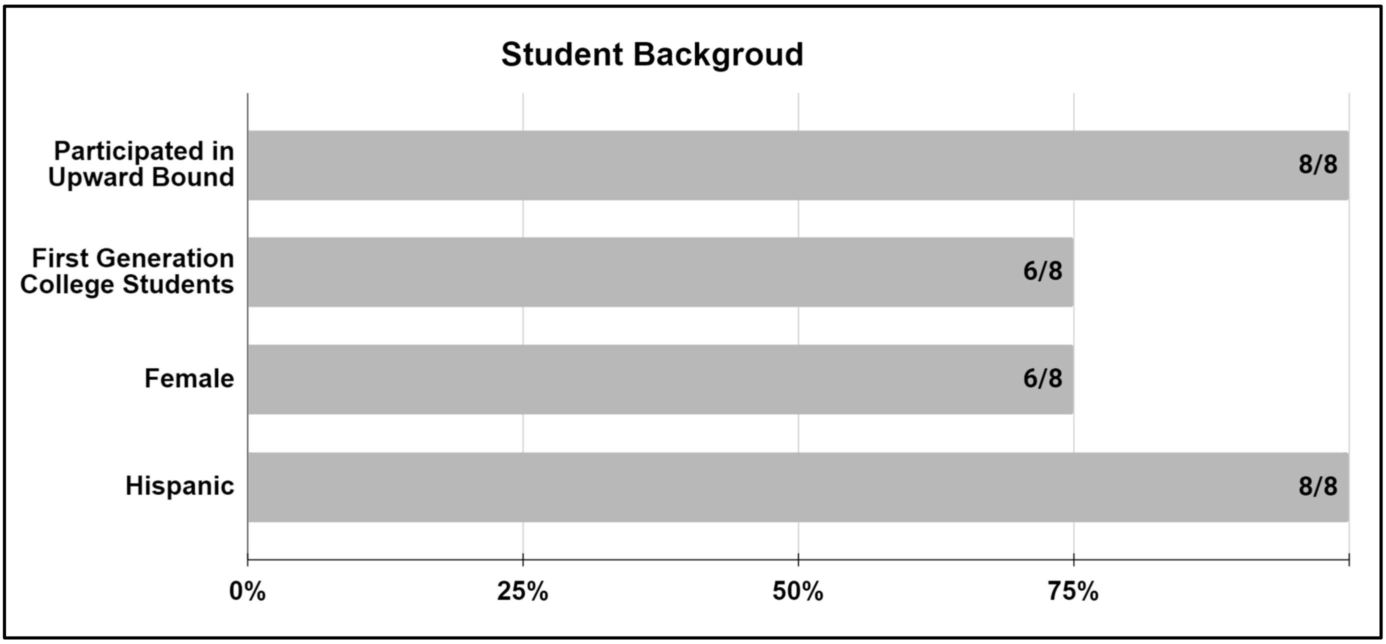

Figure 2. Background information for participants. Eight students who attended the Upward Bound program in high school and are currently attending New Mexico Tech participated in our interview questionnaire. Six out of eight were first-generation college students. Six students identified themselves as female and two as male. All participants identified themselves as of Hispanic origin.

Participant *Jade* had an excited and nervous outlook on her college experience. She is a first-generation college student. *Jade* has experienced much support from her family, teachers, and Upward Bound with her transition into college. *Jade* worked for Upward Bound and was involved in research at NMT. She did well in school and graduated in Spring 2024. *Jade* is using her bright spirit and mind to conquer her goals. She was driven by the difficulty of Tech and enjoys the challenges she faces.

Participant *Meg* is a first-generation student and had an excited but nervous outlook on her college experience. *Meg* had much influence and support from her high school, and her counselor helped her with college admission. She has also experienced much support from Upward Bound with her transition into college and has worked for the Upward Bound grant project while at Tech. She learned to continue to strive for success and her experiences thus far have shown that she does well in school.

Participant *Kim* had a neutral outlook on her college experience and is not a first-generation college student. Kim was initially looking at other schools and had some doubts about Tech, but with the support of mainly Upward Bound, she started to embrace Tech and sought help along the way. She was employed by the Upward Bound program. Her experiences thus far have shown that she does well in school and is driven by her goals.

Participant *Greg* had a confident outlook on his college experience even though he is a first-generation student. *Greg* has experienced much support from his mother and Upward Bound with his transition into college. He took action in reaching out for help in making his experiences positive, and he has thus far done well in school. *Greg* is involved in student clubs and internships, which he says gives him his purpose and drive. He is also driven by his educational desires. Because of his engineering club's involvement, he already sees potential career opportunities in the near future.

Participant *Sam* had a confident outlook on his college experience and he is also a first-generation student. *Sam* has experienced much support from his family, teachers, and Upward Bound with his transition into college. His experiences thus far have shown that he does well in school and took the initiative in reaching out for support. *Sam* has had a lot of influence from his friends who attended Tech and Upward Bound, and he believes this is the push he needs to keep working toward his goal. He has had great experiences thus far and foresees many more to come.

Participant *Cleo* had a nervous outlook on her college experience and mentioned she did not come from a first-generation college family. *Cleo* has experienced much support from her parents and Upward Bound with her transition into college. Her experiences thus far have shown that she does have struggles, i.e., got suspended due to not meeting the minimum GPA requirement, but since then has successfully returned. Although *Cleo* experienced some intense struggles with Tech and took a major fall with the help of her friends, family, and Upward Bound, she is back on track for her degree completion. The Upward Bound grant program supported *Cleo* with a part-time job when she returned to college.

Participant *Kylie* is a first-generation student and had a nervous outlook on her college experience. *Kylie* has experienced much support from Upward Bound with her transition into college. At the time of this interview, *Kylie* had been a student for three months. She has recently accepted a summer job with Upward Bound. To overcome the stress of the first semester, she mentioned receiving mental health counseling services at Tech.

Participant *Tory* is a first-generation college student and, like other female participants, she had a nervous outlook on her college experience. Upward Bound has helped with her transition into college. However, her experiences thus far have shown that she struggled and got suspended in 2024 because of not meeting the minimum GPA requirements. She is trying to work her way back to college and is getting support from a temporary job with Upward Bound.

3.3. Deciding Factor to Attend College

Because the majority of our participants were first-generation college students, asking about their decision to attend college was deemed important to our study. Therefore, we asked participants to "Tell me about when you first decided to attend college. Any key players in the journey and how they were/were not supportive?" As shown in Figure 3, six out of eight participants said their parents were supportive (displaying emotional aid); one of the comments: "*Mom was the key player, she never got to finish college so I'm doing it for her*" (commented by *Kylie*). Only three out of eight participants said their high-school teachers were supportive of their decision to attend college, suggesting academic outreach. One significant comment: "*Chemistry teacher from sophomore year, very influential, also an elementary gifted teacher*" (commented by *Jade*). Six out of eight NMT students said their decision to attend college was supported by the Upward Bound program staff, suggesting strong academic support through this program. Some student comments: (1) *Started doing upward bound and had a tour that really sold me on NMT, I like being a little bit away from home. The Director at UBMS reached out a lot and gave lots of contacts* (commented by *Meg*) and (2) *During Upward Bound Bridge summer (after high school graduation) the Residential Assistant (RA) helped with college selection and banweb and other stuff since I enrolled at the very last minute* (commented by *Kim*). Six out of eight students mentioned they were self-motivated to attend college, aligning with an intellectual theme. Some of the comments from these students: (1) *I always knew I wanted to go to college, the only way I wouldn't be able to would be for financial reasons* (commented by *Tory*); (2) *I knew that when I was done with high school it was time for college* (commented by *Cleo*); and (3) *I read a book about forensics that made me fall in love with it. I wanted to pursue a forensic science degree but attended NMT due to financial reasons* (commented by *Kim*).

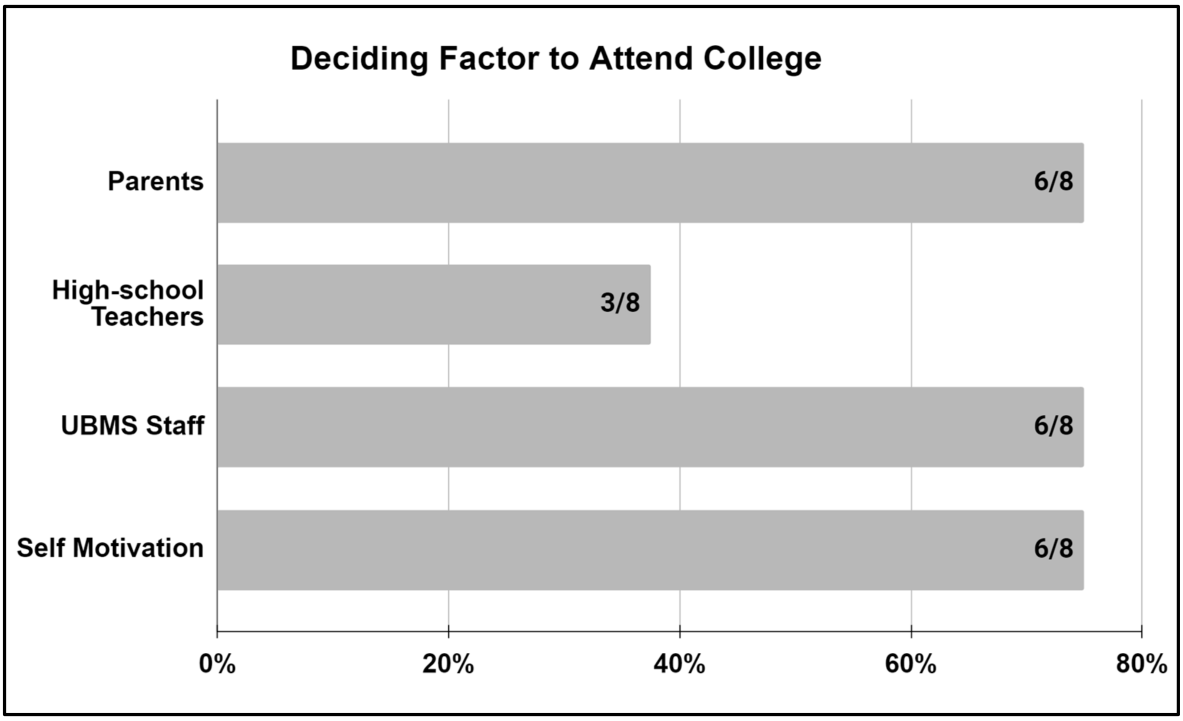

Figure 3. Who helped students to decide to attend college/New Mexico Tech. Six out of eight students said their parents or Upward Bound Math or Science (UBMS) program staff supported them, or they were self-motivated to attend college. Only three out of eight students said their high school teachers supported them in deciding to attend college.

3.4. Reasons to Select New Mexico Tech (NMT) for Postsecondary Education

Once students decided to attend college, we wanted to know why they chose NMT. Their reasons included emotional and financial support. Hometown's proximity to the university played a significant role in seven out of eight participants' decision to attend Tech (as shown in Figure 4 below). Three out of eight participants stated that not only was Tech close to home, but it would help save money (financial adjustments). Comments are as stated: (1) *At first, I wanted to get out of town away from Socorro, but the financial part of staying home was super useful* (commented by *Kim*); (2) *It affected it due to being able to stay home and save money and also have my family close by* (commented by *Greg*); and (3) *Huge decision maker because I could save money on housing and don't really pay much for bills and food, financial reasons were a big deciding factor* (commented by *Tory*). A total of three participants mentioned family as a reason to choose NMT (emotional support). Most participants stated that being close to home was the number one factor in deciding to attend Tech; however, saving money was important to them as well. The choice to attend NMT was a balance of both emotional and financial reasons.

Academic reasons were also apparent as to why participants chose NMT. At least for the past two decades, NMT has been hosting state-level competitions for the Science Olympiad and Science Fair. Each year, many middle and high school students from across the state of New Mexico participate in these events and get exposed to the NMT campus. We wanted to know if being at the NMT campus through these events encouraged them to pursue their postsecondary education at NMT, so we asked, "Did your participation in UBMS, Science Olympiad or any other events help your decision to attend NMT?" Being involved with UBMS played a significant role in all eight participants' decision to attend college, specifically Tech. Three of the comments are as follows: (1) *Helped with exposure to Tech and figured out what classes look like, and I figured out where every building was* (commented by *Kylie*); (2) *If I didn't do upward bound I wouldn't have come to Tech* (commented by *Kim*); and (3) *At first, I thought I was going to go to Colorado for school but then once I stayed at NMT* *during the UBMS summer program and I saw a lot of different departments and I was like oh maybe I do want to come here cuz they have Environmental Engineering what I wanted to do* (commented by *Meg*).

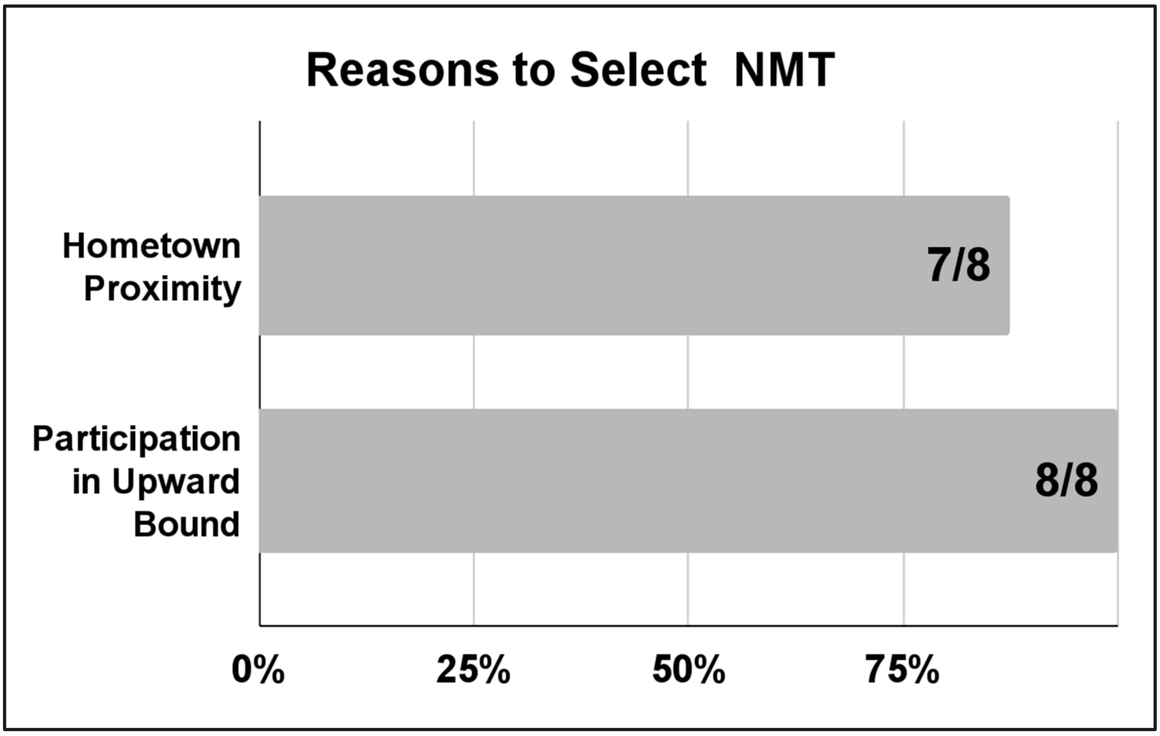

Figure 4. Seven out of eight participants said NMT's proximity to their hometown was a reason to select NMT for their postsecondary education. All eight participants cited their participation in the Upward Bound Math and Science (UBMS) program as the biggest factor in selecting NMT.

3.5. Conversations before Starting College

Being a first-generation college student, one may need added support in preparing for college, therefore participants were asked about conversations they had as they were preparing for their first semester at New Mexico Tech (NMT) and with whom. Preparation and who gave advice varied amongst the answers; however, emotional adjustments were apparent when having these conversations. Two out of eight participants stated that a family member helped them prepare for their first semester; their comments are as follows: (1) *My older sister helped me prepare for how stressful classes are and how to handle the faculty at Tech* (commented by *Kylie*) and (2) *Lots of conversations with my mom and UBMS faculty* (commented by *Greg*). Support from an academic perspective was received from UBMS and/or high school staff. One participant commented that they had conversations with a career guidance counselor at high school that helped them get ready for college. Two out of eight participants had conversations with "a lot of people", including UBMS staff. One of the comments reflects this: "*I had lots of people including my middle and high school teachers who were previous NMT students that helped my transition, and upward bound staff who were helping, I also had conversations concerning 'adult things*" (commented by *Tory*). This suggests that participants received social assistance through their transition period. One participant did not recall: "*Can't recall any conversations, and was pretty unaware of the situation I was going to be in*" (commented by *Cleo*).

Emotional and intellectual adjustments were apparent when participants were asked about how they felt when preparing for their first semester at NMT; three stated they were excited but nervous or scared. A significant comment from a participant was "*I felt super nervous and was scared of failing but realized that I am human, NMT is a hard school and I've given myself grace*" (commented by *Meg*). Two participants did not feel nervous, excited, or scared. One comment, as noted, was "*Felt like it would be a breeze, and then was totally shocked as to how hard it was, but I was super motivated*" (commented by *Greg*). Interestingly, all female participants (six out of eight) said they were either nervous or scared, and on the other hand, the two male participants did not use these terms.

3.6. Support from NMT

The transition from high school to college is a critical period for students who may need support not only from family and friends but also from the university staff. The support coming from New Mexico Tech was dependent on different departments with the main goal of aiding students. Participants were prompted to give us their thoughts on five departments: housing office, office of admissions, registrar's office, financial aid, and department for their major. We asked a series of questions about various offices that provide student support. The participants were asked to rate the department on a Likert scale of 0–3 or 0–4 and give comments related to their respective scores. However, during our independent analysis of the data, we recognized that the ratings were not aligning well with their comments; therefore, in describing their experiences in this section, we only focused on their comments, finding that all six themes were apparent with emotional being the dominant adjustment. Students' original rating scores are listed in Figure S1 in the Supplementary Information document.

Each of the five departments has a mission statement showing what they aim to provide for New Mexico Tech students. "The housing department creates a safe, supportive, and equity-minded environment by creating holistic growth opportunities that align with the Division of Student Life's Mission" [19]. Most of our participants (six out of eight) said they did not need housing support due to the proximity to their hometown.

"The NMT Office of Admissions assists students as they progress through the admission process and helps students decide if New Mexico Tech is the right fit for them and their academic journey" [20]. When asked about "Admissions support", all participants mentioned that they did not receive much support from NMT's Admission Office. One participant mentioned receiving early admission during their sophomore year of high school. Two students mentioned getting help from the UBMS staff with comments: (1) *I did not have any help from NMT, only from UBMS* (commented by *Greg*) and (2) *I did not get much help from NMT, but at the same time, I didn't need much help because of the college bridge program from UBMS* (commented by *Tory*). One participant also mentioned "*I didn't need them*" (commented by *Sam*).

"The registrar's office upholds academic policies, preserving the integrity of academic records, and provides ample support for students from the application stage to degree completion" [21]. When we asked about "Course registration support from the Registrar's Office", one significant comment from a participant: "*Doesn't feel like me or my peers got a lot of support from the registrar's office. Feels like they just throw forms at you and tell you to talk to someone else. Also, mostly I did my own registration*" (commented by *Jade*). It is important to note that all three authors had similar experiences with this office over the years. During the last seven years, the registrar's office went through a high turnover with four different registrars; however, the issues persist.

"The financial aid office assists with financial barriers for those who wish to pursue a post-secondary education. New Mexico Tech makes an effort to help education be affordable for everyone through institutional scholarships, financial aid, and student employment" [22]. When participants were asked about "Financial Aid office support", we received some positive and other jaw-dropping responses including (1) *They were always open to answering questions, and super responsive with emails. Been able to speak with someone in person and they've always helped with scholarships* (commented by *Jade*); (2) *They gave me two different student ID numbers, which created issues with registration, and I actually had to pay back $500 for their mix-up before I could register again* (commented by *Greg*); and (3) *They switched up on how they did business after my first year, they stopped processing my FAFSA and now I'm paying out of pocket without financial aid due to their mistakes* (commented by *Tory*).

"The department for individual major's aids with student education by inspiring diverse students to challenge themselves by setting goals, making informed decisions, developing professionally and personally, and taking ownership of their education" [23]. When we asked about the "Ease of choosing a major and support from the department", four participants mentioned either they already knew their major or did not need help from the department. Three students mentioned that their advisor or department was really helpful with the following comments: (1) *I registered super late and got a lot of assistance with that process from my advisor* (commented by *Kim*); (2) *There was the ease with switching from biomedical to biology* (commented by *Cleo*); and (3) *My first advisor was not helpful but when they switched to a more senior faculty advisor I had a great experience* (commented by *Tory*), suggesting strong academic support from a majority of NMT faculty members.

3.7. Adjustments to New Mexico Tech

The demands and pressures of being a first-year college student are stressful not only for first-generation college students but also for all other students as well; therefore, asking about how their first semester went was important. Academic, intellectual, emotional, and social adjustments were identified from the students' comments because of the intensity of the coursework. When asked about how their first semester went, six out of eight participants said the transition was hard due to the workload (academic adjustment). Some of the comments we received include (1) *Rough at the beginning, every class needs your undivided attention, and everything is time-consuming. Feels like there are not enough hours in the day to get everything done* (commented by *Greg*) and (2) *I thought the adjustment would be quick, but it felt like the wave of responsibility was intense and I had no security, hard to deal with the transition into adulthood* (commented by *Meg*). Participants mentioned they found various support systems, and their comments were (1) *Family, love, and work balance. Hybrid classes during my senior year were definitely a transition to being in person and having responsibility but still working to find a happy balance between work and life* (commented by *Tory*) and (2) *Adjusting was aided by finding a support system here* (commented by *Jade*, who started NMT in the Fall of 2019). The participants mentioned academic, social, emotional, cultural, and intellectual adjustments.

3.8. Did the Student Reach Out?

To be successful at New Mexico Tech (NMT) or any university, students need support, especially with academic, intellectual, and social adjustments, therefore reaching out to different entities can help. Students were prompted to look at their own initiative with NMT and the help it offers. Each student has access to an academic advisor, the Office of Student Learning (OSL), and tutoring at individual departments. These are the three main contributors to success at NMT. Each student within their department is assigned a random faculty advisor who will help them with their schedule and college degree plan. There are required/encouraged visits once a semester to talk about the following semester's course load and the overall progress of the degree. OSL offers tutoring and helps students organize review study sessions. Tutoring for a variety of subjects is available for students. Various departments also offer additional tutoring hours. We asked participants how many times they met their advisor and if they attended any tutoring sessions during their last semester. As shown in Table 1, all students attended meetings with their faculty advisor; however, only three out of eight students attended tutoring sessions. Interestingly, the students who mentioned attending tutoring at OSL also attended tutoring sessions at the departments. Although everyone mentioned the NMT coursework was hard, only three out of eight students reached out to obtain additional tutoring help. Our data suggests that universities need to find unique approaches to encourage more students to utilize these academic success resources.

Table 1. This table shows each of the eight student participants and the number of times they attended their advisor's office, office of student learning (OSL), and tutoring services at the departments during their previous semester at New Mexico Tech.

Students	Advisor	OSL	Tutoring	First Semester at NMT
Jade	2–3 Times	0 Times	0 Times	Fall 2019
Meg	2–3 Times	2–3 Times	1–2 Times	Summer 2022
Kim	2–3 Times	3–5 Times	1–2 Times	Fall 2022
Greg	1–2 Times	0 Times	0 Times	Fall 2021
Sam	1–2 Times	0 Times	0 Times	Fall 2021
Cleo	1–2 Times	0 Times	0 Times	Fall 2021
Kylie	3–5 Times	0 Times	0 Times	Fall 2023
Tory	2–3 Times	1–2 Times	1–2 Times	Fall 2021

3.9. Student Experience with General Education Courses

NMT is a STEM-focused institution, and it is widely expected that the workload is intense, therefore academic adjustments were needed to meet the demands of the preliminary courses. However, because of the difficulty level, emotional adjustments were also needed to be able to adapt to the stressors that come with the coursework; therefore, we asked about the general courses that all NMT undergraduates had to take. General Education core curriculum requirements include courses in Humanities, Mathematics, and Basic Laboratory Sciences, which all undergraduate students must complete to graduate [24]. Participants were asked about General Education courses. The three-course areas included in this research are Communications, Mathematics, and Basic Laboratory Sciences. For each area, participants were asked five questions: (1) if they completed the course, (2) what was the level of difficulty, and (3) how easy it was to approach the instructor. These two questions used a Likert score scale with 1 being the least to 4 being the most difficult for the answers: (4) how many times have you attended office hours and (5) how many times have you attended tutoring sessions for a certain course with a scale of 0 to 6 or more times. The detailed information is available in a Supplementary File. In this section (Table 2), we will summarize and compare the average level of course difficulty to the number of office hours or tutoring sessions attended. The total number for each response reflects the number of students who have taken this course as of Fall 2023.

Table 2. This table shows the scores of participants who completed the general education courses. A Likert scale of 1 (easy) to 4 (difficult) was used to obtain a numerical score from students for the level of difficulty and ease of approaching the instructor.

General Education Courses	Level of Course Difficulty (Scale of 1–4)	Ease of Approaching Instructor (Scale of 1–4)	Office Hours (0, 1–2, 3–5, 6 or More Times)	Tutoring (0, 1–2, 3–5, 6 or More Times)
English 1	3 said 2 4 said 1 1 didn't take	2 said 2 5 said 1	3 said 1–2 4 said 0	1 said 1–2 6 said 0
English 2	1 said 1 4 said 2 1 said 4 (took it twice)	2 said 1 2 said 2 2 said 4 (first time 4, second time 1)	2 said 1–2 4 said 0	All 6 said 0
Technical Writing	2 said 1 2 said 2	3 said 1 1 said 2	1 said 3–5 3 said 0	All 6 said 0
Gen Chemistry I	5 said 2 2 said 3	4 said 1 1 said 2 2 said 3	2 said 1–2 2 said 3–5 3 said 0	2 said 1–2 2 said 3–5 1 said 6+ 1 said 0

Table 2. *Cont.*

General Education Courses	Level of Course Difficulty (Scale of 1–4)	Ease of Approaching Instructor (Scale of 1–4)	Office Hours (0, 1–2, 3–5, 6 or More Times)	Tutoring (0, 1–2, 3–5, 6 or More Times)
Gen Chemistry II	1 said 1 1 said 2 4 said 3 1 said 4	3 said 1 3 said 2 1 said 3	1 said 1–2 2 said 3–5 4 said 0	4 said 1–2 1 said 3–5 1 said 0
Physics I	1 said 1 2 said 2 2 said 3	All 5 said 1	2 said 1–2 1 said 3–5 2 said 0	2 said 1–2 1 said 3–5 2 said 0
Physics II	1 said 2 2 said 3	All 3 said 1	2 said 1–2 1 said 0	1 said 3–5 1 said 0
Calculus I	1 said 1 1 said 2 4 said 3	3 said 1 1 said 2 2 said 3	3 said 1–2 1 said 3–5 1 said 6+ 1 said 0	2 said 1–2 1 said 3–5 3 said 0
Calculus II	All 3 said 4	2 said 2	1 said 1–2 1 said 3–5 1 said 0	1 said 1–2 1 said 3–5 1 said 0

3.10. The Student's Experiences Thus Far

It was important to ask students about their low and high points because it determined if the students had the desire to persevere through challenging and stressful times. To identify ongoing issues for first-generation and or low-income students, we asked them to give us examples of low and high points during their time at NMT. Seven out of eight students said failing a class/exam/test was the low point, suggesting emotional and intellectual adjustments. One student who started college about three months ago mentioned that issues with FAFSA and the internet were their lowest points so far. One specific comment highlights that these students do not reach out for help, especially in the beginning: "*Not performing well my first year and isolating myself from the stuff NMT offers and didn't connect me with any peers or took advantage of OSL or meeting an advisor*" (commented by *Cleo*). High points included building community and support systems, being able to do research, finding campus jobs, activities such as Swing Dancing, and BAJA, as well as getting good grades and passing tests, all pointing towards academic, social, emotional, intellectual, and financial adjustments. Overall, one participant graduated in the spring of 2024 and six students are on track. One of these participants returned to NMT after being suspended due to not meeting the minimum GPA requirement. Upon their return, this participant was supported by a part-time job through the UBMS grant, and they are now on track to complete their degree program. Unfortunately, one other participant was suspended for the Spring 2024 semester due to the same academic reasons. However, the Upward Bound program supported them emotionally, socially, and financially by providing them with a temporary job. The UBMS staff is committed to continuing to help until this participant successfully returns to college.

3.11. Ways the Students Felt Supported

Being a student right out of high school and into college can be a tough adjustment in itself, much less being a first-generation/low-income Hispanic student. In general, more support is needed for these students to be successful, especially for emotional, academic, and financial adjustments, so participants were asked what support they received from NMT and how they can be better supported. Support for the eight participants varied in their answers. Some participants were vague about the support they received, and others were too specific. One comment was both: "*There is security in asking questions or doubts because I know that there is help no matter what, however, most of my support came from UBMS*" (commented by *Meg*). For the most part, the participants stated that NMT had the support that they needed, as reflected in these comments: (1) *Teachers will always care about your* *success and there are clubs and student peers that have been supportive. There is a lot of comradery with students* (commented by *Greg*); (2) *advisor is helpful and so are study groups and other support systems* (commented by *Cleo*); and (3) *OSL (Office of Student Learning) was a big help with different classes* (commented by *Kim*). Two out of eight participants didn't seek much support: (1) *didn't really look for support* (commented by *Sam*) and (2) *didn't need a lot of support, but the counseling office was helpful* (commented by *Kylie* who started college about three months ago).

Participants were then asked how they could be better supported, and, according to their answers, academic and emotional adjustments were dominant. Five out of eight students gave ideas on what could have been done to help their first semester go smoothly. Two out of the five stated that NMT should offer summer classes so that they could be better prepared for higher-level courses. The comments were (1) *feels like students like me who weren't as prepared as others, maybe Tech should offer starter classes or more summer classes* (commented by *Jade*) and (2) *Offer online classes during the summer so people can catch up and be at the same level as other students and be on track* (commented by *Kim*). One student wanted students to be treated differently: "*They have a lot of steps to get to an answer and feels like admin, registrar,* etc., *should be more forgiving with paperwork and the process they make you go through that makes you feel like a subject rather than a person*" (commented by *Meg*). One of the five stated, "*More funding for more design clinics and projects for students*" (commented by *Greg*); and another "*Later hours of working, later tutoring hours like 8 or 9 pm, hard to finish stuff at night when there's no one to ask*" (commented by *Tory*). Three participants stated that there is nothing to better support them. One commented, "*In the first semester there's not much you can do for the transition of students, just have to do it*" (commented by *Sam*) and the other two simply said, '*none*' (commented by *Cleo* and *Kylie*).

3.12. Barriers to Success

Barriers can be a challenge for college students. Participants were asked about any barriers faced while being at NMT and anything affecting their desire to stay. When asked about any barriers they faced while being at Tech, all eight participants stated that the classes were difficult or they didn't feel prepared academically and intellectually. One participant did not do as well as they hoped but persevered: "*Got suspended, had to readmit and get the financial situation settled before I could come back, Tech was very understanding of my situation*" (commented by *Cleo*). One participant felt that her main barrier was cultural: "*It's hard to find any Spanish-speaking people on campus, I feel isolated from my culture*" (commented by *Tory*). This is surprising since NMT is a Hispanic Serving Institution (HSI). One participant did not discuss the classes being difficult but felt hindered emotionally: "*Being scared of being wrong, feels like Tech and the peers aren't forgiving with being wrong*" (commented by *Meg*). Since Tech is male-dominated (69%), one of the participants experienced this by stating, "*Having to face difficult classes I didn't feel prepared for also being a female here and the challenges of dealing with men looking down on me*" (commented by *Jade*). All three authors being female on a male-dominated campus felt somewhat similar to the comment from *Jade* at some point during their time at NMT.

Continuing college to completion for first-generation/low-income Hispanic students is challenging; therefore, we asked the participants if there was anything that has affected their desire to stay at NMT. All eight participants answered that they have the support to continue, and, therefore, adjusting emotionally. One participant gave two perspectives in their answer: "Negative: *getting annoyed with several things at Tech is something that's hurt my desire.* Positive: *my support has helped me to push through and keep going*" (commented by *Meg*). Another participant stated, "*Sources of support have helped me stay in school; the barriers did not affect my desire because barriers are part of life*" (commented by *Greg*). Finding support was one of the commonalities noticed in our study. All participants claimed that UBMS helped guide their way to attend college, and finding support systems drove them to remain in college thus far.

3.13. Additional Comments from Participants

To provide students with additional avenues to include any other information based on their experiences so far at NMT, it was important to ask, "Is there anything else I haven't asked about that you feel would be relevant to your story and pertinent to share?" Three students did not provide any additional comments. The remaining comments are summarized here: (1) *Being a first-generation college student has made me who I am today, helps me help others, and I want others to reach for the stars* (commented by *Jade*); (2) *Tech should focus more on art departments and show more incentive to support creativity, I feel like art helps with every degree* (commented by *Meg*); (3) *Being able to communicate with teachers and peers is so important, it's very important to communicate*. (commented by *Greg*) (4), *Readmission was simple, and Tech is understanding* (commented by *Cleo*); and (5) *Coming to Tech was hard because I felt like I didn't know if I belonged, it's more so about being hardworking than it is being super smart* (commented by *Tory*).

4. Discussion

This study is based on detailed one-on-one interviews with eight current New Mexico Tech (NMT or Tech) students who participated in the Upward Bound Math and Science (UBMS) program as a high school student. NMT is a small STEM-research-focused Hispanic Serving Institution (HSI) with only 1169 full-time degree-seeking undergraduate students enrolled (NMT IPEDS data 2022–2023 [2]). We acknowledge that this is a pilot study; however, based on NMT's smaller total undergraduate population, our total participant number of eight is significant.

RQ#1: What are the barriers faced by low-income and/or first-generation students at a STEM-focused HSI and how are they being supported? Our participants adjusted to a new way of life once they decided to attend college and once they began coursework at NMT. All six adjustment areas that first-year college students experience, including academic, cultural, emotional, financial, intellectual, and social [8,9], were touched on at some point during the students' interviews. Displaying academic and emotional adjustments was evident in the comments from participants when they described the intense workload and their struggles with the various challenges of adulthood. Adjustments for intellectual and social aspects were made by finding support groups and reaching out to family and fellow students or staff. Financial factors were mentioned by the majority of participants when they were selecting a college close to home. A cultural factor was mentioned by one student when not finding Spanish-speaking people on campus given that NMT is a Hispanic Serving Institution. Several participants mentioned some support from NMT faculty advisors and other campus offices. However, the majority of participants were dissatisfied with the academic support offices, specifically the Office of the Registrar and Financial Aid. All female participants (six out of eight) mentioned they were either nervous or scared, and on the other hand, the two male participants did not use these terms and appeared confident in their overall college experience. Two of the six female participants were suspended for a short period due to not meeting minimum GPA requirements. This is to be expected due to NMT being a male-dominated (69% undergraduate population) institution as also shown by previous recent research [25] that STEM programs are less popular among female students, and they are less likely to graduate on time. Institutions should review their policies to provide more support to reduce this achievement gap.

Six out of eight participants worked for the Upward Bound grant program at some point during their time at NMT. Through this, they not only found financial aid but also built a community of fellow low-income and/or first-generation students to support each other's academic, social, emotional, intellectual, and cultural adjustments. The Upward Bound program helped all participants during their transition to college. Moreover, the program helped at least two participants when they struggled academically to persevere and return to college. These results align with the recent findings that low-income and/or first-generation underrepresented college students persevere in STEM when they develop a sense of belonging and academic hope [26,27].

RQ#2: What are some of the ways to improve the graduation rates of all students? Even with a small study, several outcomes for the institution came out clearly when multiple students mentioned the same concerns. Student support services, specifically the Office of the Registrar and Financial Aid, need to improve practices to better support all students. Students mention not being prepared for classes, although at NMT, a typical practice is that students complete a math competence test before their first semester, and based on the results, they are placed in appropriate courses. This practice needs to be reevaluated. Offering basic-level courses the summer before the academic year starts and some additional support from faculty members will improve outcomes for first-generation/low-income students. Based upon evidence-based models, Pearson et. al. recommends several strategies to improve outcomes for low-income, first-generation, and underrepresented STEM-degree support programs [28].

Another important finding from this study is that first-generation students do not reach out to ask for help, as shown by their attendance during office hours or tutoring in Tables 1 and 2. Faculty members need to reach out more to make sure students feel welcome and talk to them when they need help as this approach has previously been shown to improve student outcomes [29]. For example, as an instructor at NMT, T.A. noticed a student was absent for several classes and contacted them to see if they were doing okay and to let them know that she was worried about them. It turned out that the student was okay and thankful that someone cared enough to reach out to them. On several occasions, T.A. helped students deal with personal issues they were going through, and they successfully completed the class. M.K. noticed most students do not come to faculty offices to ask questions, so she scheduled office hours right after her classes. If students are struggling in class, M.K. invites them to talk outside the classroom and ask how she can help them. In her short time teaching at NMT, M.K. noticed students perform better once they realize that instructors care about their success. Simply reaching out by showing that faculty cares and supports students in any situation will help students keep up their morale to continue to do well in college. More data and expanded studies are needed to provide further recommendations on improving outcomes and to increase NMT's overall graduation rate of ~55% from the last five years. One example of a new strategy for next academic year, Author M.K. is going to transform a first-year Chemistry seminar course into a College Success course. She plans to utilize relevant strategies from recent education research [30,31].

The most positive outcome of the study was that the Upward Bound program was the single most important factor in all eight participants' decision to attend college. The UBMS program not only provides initial support during student's transition to college but, later on, supports them in various other ways. Six out of eight participants were employed as student workers by the UBMS grant program. Eventually, these students found a community of fellow students through the UBMS program and built their campus support systems. As shown by previous research, peer support networks mitigate many challenges that first-generation students face [32,33]. In conclusion, NMT's UBMS program not only helped students get admitted to college but it is also helping first-generation and/or low-income students' retention and persistence.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/educsci14080828/s1, Figure S1: This image shows a quantitative view of the scores for the four acceptable departments for our study. The top left corner shows the score for the individual department of major, the top right corner shows the scores for the registrar's office, the bottom left corner shows the admissions office, and finally the bottom right corner shows the financial aid scores. Figure S2: Participants were asked about General Education courses. The three-course areas included in this research are Communications, Mathematics, and Basic Laboratory Sciences. For each area, participants were asked five questions: (1) if they completed the course, (2) what was the level of difficulty, and (3) how easy it was to approach the instructor. These two questions used a Likert score scale with 1 being the least to 4 being the most difficult for the answers, (4) how many times have you attended office hours and (5) how many times have you attended tutoring sessions for a certain course with a scale of 0 to 6 or more times. This data corresponds to Table 2.

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Article

Modelling Student Retention in Tutorial Classes with Uncertainty—A Bayesian Approach to Predicting Attendance-Based Retention

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Abstract: A Bayesian additive regression tree (BART) is a recent statistical method that blends ensemble learning with nonparametric regression. BART is constructed using a Bayesian approach, which provides the benefit of model-based prediction uncertainty, enhancing the reliability of predictions. This study proposes the development of a BART model with a binomial likelihood to predict the percentage of students retained in tutorial classes using attendance data sourced from a South African university database. The data consist of tutorial dates and encoded (anonymized) student numbers, which play a crucial role in deriving retention variables such as cohort age, active students, and retention rates. The proposed model is evaluated and benchmarked against the random forest regressor (RFR). The proposed BART model reported an average of 20% higher predictive performance compared to RFR across six error metrics, achieving an R-squared score of 0.9414. Furthermore, the study demonstrates the utility of the highest density interval (HDI) provided by the BART model, which can help in determining the best- and worst-case scenarios for student retention rate estimates. The significance of this study extends to multiple stakeholders within the educational sector. Educational institutions, administrators, and policymakers can benefit from this study by gaining insights into how future tutorship programme student retention rates can be predicted using predictive models. Furthermore, the foresight provided by the predicted student retention rates can aid in strategic resource allocation, facilitating more informed planning and budgeting for tutorship programmes.

Keywords: Bayesian approach; tutorship programme; education data analytics; ensemble

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1. Introduction

In today's higher education landscape, retaining students has emerged as a significant challenge. Statistics reveal that nearly 40% of students are not retained within their academic institutions or classes over time, indicating the urgency of addressing this issue [1]. Consequently, educators and researchers have undertaken numerous studies to explore innovative approaches to student retention. One approach that has gained significant attention is data analytics. Educational institutions have begun recognizing the potential of data analytic solutions in ensuring student success and retention [2]. Student retention, in this context, is defined as the percentage of students who re-enrol from one academic year to the next [1]. The term data analytics refers to the systematic examination of raw data within a specific context to uncover meaningful patterns, correlations, and trends that can be translated into actionable insights [3]. The application of data analytics in the education domain is commonly referred to as educational data analytics [3].

Recent studies demonstrate that higher education institutions that develop predictive and diagnostic analytical solutions to address student retention can benefit from enhanced reputation, better ranking, and financial stability [3–5]. Low retention rates negatively impact an institution's financial and institutional stability [4,6], demonstrating the need for educational institutions to develop and implement effective data analytic strategies to improve student retention rates.

While existing work in educational data analytics has primarily focused on the development of predictive models, such as logistic regression, support vector machines, random forest, and decision trees, for the purpose of predicting student retention, a notable gap exists in the consideration of student retention as a multifaceted problem [1,5,7,8]. Student retention encompasses more than just predicting whether a student can be retained from one year to the next; it also extends to various programmes offered by institutions, including tutorship programmes (TPs).

TPs have become an essential part of higher educational institutions, as they provide a supportive environment for students to improve their academic performance [9]. TPs offer personalized attention, access to resources, and mentorship opportunities, which can enhance students' understanding of complex concepts and development of study skills [9]. Moreover, TPs can increase students' confidence in their abilities, leading to improved academic and personal outcomes [9]. However, to ensure the effectiveness of tutorship programmes, it is crucial to ensure retention in tutorial classes. This study defines student retention in tutorial classes as the percentage of students retained in tutorial classes over a specified period. High retention rates in TPs not only ensure that students continue to benefit from personalized instruction and support, but also help to improve graduation rates [10]. In this way, TPs play a critical role in improving student success and supporting their academic and personal development [10].

Despite the progress made in using educational data analytics to tackle student retention, gaps in literature persist. One significant gap pertains to the absence of predictive models in education that can offer reliable predictions using uncertainty quantification approaches [11]. The current predictive models used in studies lack probabilistic information, which leads to overly confident or incomplete decision making. Uncertainty quantification provides a framework for estimating and integrating probabilistic information into predictive models [12,13]. By disregarding uncertainty, these studies fail to assess the confidence associated with predictions. Uncertainty information is crucial for decision making and risk assessment. Ignoring uncertainty can result in incomplete or deceptive decision-making [12,14]. Decision makers in education need not only point predictions but also a measure of certainty in those predictions. Neglecting uncertainty may result in underestimating risks, overestimating benefits, or making suboptimal choices [14].

To address these gaps, this study proposes the adoption of a Bayesian approach to model and predict attendance-based retention in tutorial classes. Bayesian models, grounded in probability theory, provide a statistical framework for making predictions and decisions. Notably, Bayesian models offer several benefits over traditional predictive models such as logistic regression, support vector machines, random forest, and decision trees. These benefits include the ability to incorporate prior information, quantify uncertainty, and handle limited data [12,14].

The rest of this paper is organized as follows. Section 2 presents the literature review, covering types of data analytics in higher education, including academic analytics, educational data mining, and learning analytics. Bayesian modelling and the use of predictive analytics in modelling student retention are also discussed. Section 3 describes the materials and methods, focusing on the Knowledge Discovery in Databases (KDD) framework, which includes data collection and understanding, data preprocessing and transformation, modelling using random forest regressor and Bayesian additive regression trees, and evaluation. Section 4 presents the results, including descriptive analysis, model evaluation, and the highest density interval estimates for the BART model. Finally, Section 5 provides the conclusion.

2. Literature Review

2.1. Types of Data Analytics in Higher Education

The expansion of data analytics in higher education is being driven by the necessity to create innovative solutions based on data to address the challenges faced in education [2,12]. This trend is further fuelled by the growing amount and diversity of data collected from both online and traditional university offerings, opening up new possibilities for using data analytics to enhance the quality of higher education [2]. Consequently, different terms that are closely related, such as academic analytics (AA), educational data mining (EDM), and learning analytics (LA), have emerged to represent distinct types of data analytics employed in higher education [2]. These terms indicate various approaches to data analytics used in the field. Furthermore, the outcomes of one type of data analytics can serve as input for another, resulting in a complex and interconnected landscape of data analytics approaches in higher education. This section will explore each type of data analytics in education and determine which ones will be used in this study.

2.1.1. Academic Analytics

Academic analytics is a term that is defined as "the application of data analytic techniques and tools for purposes of supporting institutional operations and decision making" [3]. The primary focus of academic analytics is to enhance institutional operations and decision-making processes. This process involves the use of data analytic techniques and tools at five distinct levels, namely, faculty, institutional, regional, national, and international levels [3]. It is worthy to note that academic analytics offers potential benefits to a diverse range of individuals and groups, including students, faculty, and executive officers.

The utilization of academic analytics can bring significant advantages to faculty members. Through the examination of educational data, academic analytics has the capability to provide important factors that contribute to student success, offer valuable insights into effective methods, and enhance knowledge about teaching and learning [15–17]. Student success holds a prominent position as a key performance indicator (KPI) in higher education; therefore, most faculty members are highly interested in predicting and monitoring student success. Studies have shown that student engagement indicators, such as attendance, clicks, and time spent on learning management systems (LMSs), are crucial predictors of student success [12]. Using academic analytics, faculty members can gain access to this information and use it to inform their teaching practices.

Academic analytics offers valuable support to executive officers in higher education by providing useful information on KPIs to support decision-making procedures [16]. For instance, the Director of Learning and Teaching may leverage academic analytics to obtain information on the student retention rate of tutorship programmes and the proportion of at-risk students. Armed with this information, the Director may choose to review the quality of the institution's tutorship programmes and learning and teaching strategy. Academic analytics can also help executive officers to optimize the use of resources and funds. By analysing educational data, academic analytics can identify areas where resources and funds can be allocated more effectively, leading to improved institutional performance [16].

2.1.2. Educational Data Mining

Educational data mining is defined as "the development and evaluation of data analytics methods for exploring educational data and using those methods to better understand learners and the learning environment" [3]. The primary objects of interest within the field of EDM are the methods and techniques employed for the purpose of analysing data at various levels within the educational system, namely, departmental, faculty, and institutional levels [3]. The various methods and techniques applied in EDM have been categorized into five general groups. These groups are clustering, relationship mining, prediction, discovery with models, and distillation of data for human judgement [18,19]. Prediction methods are used to forecast future outcomes, while clustering methods are applied to identify groups with similar attributes [3]. Relationship mining explores correlations between different variables, and discovery with models aims to uncover hidden patterns in the data [3]. The final group, distillation of data for human judgement, involves summarizing complex data into easily interpretable formats that can aid decision making [3].

2.1.3. Learning Analytics

Learning analytics refers to "the application of data analytic techniques and tools for purposes of understanding and enhancing learning and teaching" [3]. The primary focus of learning analytics is the learners and the learning settings, which are subject to data analysis at the levels of individual students, courses, and departments [3].

As per the Society for Learning Analytics Research (SOLAR), learning analytics can be categorized into four distinct areas, which include descriptive, diagnostic, predictive, and prescriptive analytics [20]. Descriptive analytics provides insights into past events, and they can be achieved through the examination of student feedback from surveys, as well as data that describe the student's lifecycle, such as study support, enrolments, and exams [20]. Diagnostic analytics, on the other hand, aim to identify underlying patterns in the data. This type of analytics is achieved by analysing educational data to find key performance indicators and metrics that can be used to enhance student engagement [20]. Predictive analytics focuses on understanding the future by identifying patterns in historical data and utilizing statistical models and algorithms to capture relationships and forecast future outcomes. Examples of predictive analytics in learning analytics include predicting at-risk students, student drop-out rates, and retention rates [1]. Lastly, prescriptive analytics aims to offer advice on potential outcomes and recommend choices using machine learning and business rules [20]. Through this type of analytics, institutions can make informed decisions on the best course of action to take, given the available data.

The various forms of data analytics in higher education vary in terms of their focus and the level of the education system they target. It has been noted before that the results obtained from one type of educational data analytics can be used as input for another. In this study, the primary approach to data analytics employed is a combination of academic analytics, which focuses on institutional operations and decision making at the institutional level, and educational data mining, which involves predicting student retention in tutorial classes, also at the institutional level.

2.2. Bayesian Modelling

Bayesian modelling, grounded in the principles of probability theory, provides a sophisticated and principled approach to dealing with uncertainty and incomplete information [14,21]. This section delves into the concept of modelling and the underpinnings of Bayesian modelling. Mathematical formulas are used to elucidate these concepts.

2.2.1. Bayesian Models

In the space of research and practice, models are simplified descriptions of a system or process. Models are designed to deliberately encompass the most significant or relevant variables of a system [21].

Computationally or otherwise, Bayesian models have two defining characteristics:

- Probability distributions: Probability distributions are used to represent unknown quantities, known as parameters.
- Bayes theorem: Bayes theorem is employed as a mechanism to update the parameter values based on the available data.

At a high level, constructing Bayesian models involves three main steps:

- Creating a model by combining and transforming random variables, based on assumptions about how the data were generated, using available data.
- Using Bayes theorem to condition the model to the available data. This process is called inference, resulting in the posterior distribution. While this step is expected to reduce uncertainty in possible parameter values, it is not guaranteed.

- Critiquing the model by evaluating whether it aligns with different criteria, such as the available data and domain-knowledge expertise. This step is necessary due to the uncertainties that practitioners or researchers may have about the model, sometimes requiring comparison with other models.

2.2.2. Bayesian Inference

Stated simply, inference involves drawing conclusions using evidence and reasoning [21]. Bayesian inference is a particular form of statistical inference where probability distributions are combined to derive updated distributions [21]. The process relies on the Bayes theorem to estimate the value of a parameter θ based on observed data Y.

$$p(\theta\,|Y) = \frac{p(Y\,|\theta)\;p(\theta)}{P(Y)} \tag{1}$$

The concept of likelihood $p(Y|\theta)$ involves incorporating data into the model, while the prior distribution $p(\theta)$ represents knowledge about the parameters θ prior to observing the data Y. The posterior distribution $p(\theta|Y)$, which combines the likelihood and prior distribution, captures all the relevant information about the problem. The marginal likelihood $P(Y)$, which represents the probability of observing the data across all possible parameter values, is often not computed. As a result, Bayes theorem is typically expressed as a proportionality [21]:

$$p(\theta\,|Y) \propto p(Y\,|\theta)\;p(\theta) \tag{2}$$

In Bayesian inference, a useful quantity to compute is the posterior predictive distribution [21]:

$$p(\hat{Y}|Y) = \int p(\hat{Y}|Y)p(\theta|Y)d\theta \tag{3}$$

The posterior predictive distribution refers to the distribution of future data, $\hat{Y}$, that is expected based on the posterior $p(\theta\,|Y)$, which is derived from the model (comprised of the prior and likelihood) and observed data. Essentially, this represents the data that the model predicts will be seen after analyzing the dataset. The equation for the posterior predictive distribution involves integrating over the posterior distribution of parameters, which means that predictions are made while taking into account the uncertainty associated with model estimates.

2.3. The Use of Predictive Analytics in Modelling Student Retention

This section focuses on the application of predictive analytics in enhancing student retention based on previous research. It discusses the predictive models employed and important factors considered when modelling student retention within the context of higher education.

The potential of data mining methods for developing predictive models to manage student retention in higher education was proposed by [22]. The primary aim was to identify students who require help from the student retention programme. The researchers implemented three decision tree classification models: ID3, C4.5, and ADT. Their findings indicated that the inclusion of all social, personal, environmental, and psychological variables is vital for effective prediction of student retention rates. The variables used in the models included gender, student category, secondary school grades, secondary school math grade, graduation stream, graduation grade, medium of teaching, college location, admission type, and retention.

The effectiveness of predictive deep learning techniques in analysing student learning data and predicting student retention was demonstrated by [2]. The researchers utilized the bidirectional long short-term model (BLSTM) and condition random field (CRF) deep learning techniques, which accurately predicted student retention. The researchers benchmarked these deep learning techniques against several other models, including neural network, decision tree, random forest, naïve Bayes, support vector machines, and logistic regression. Evaluation metrics such as recall, accuracy, precision, and F-score were employed to assess the models' performance. The predictive variables used to forecast retention included preparatory grade-point average (GPA), mathematics, physics, English, quizzes, assignments, statistics grade, high school, and overall GPA. The study concluded that predictive models can be valuable tools for universities to determine students at risk of discontinuing their studies.

The use of support vector machines and neural network models to predict student retention was explored by [4] with impacts and implications. The study used degree, gender, age, first generation, high school GPA, college GPA, plans to work, and ACT composite as input variables for the models. Interestingly, the authors found that high school rank, first math course grade, SAT math score, and precollege intervention programmes were useful in predicting retention. This suggests that nonacademic factors, such as preparation programmes, may have an impact on student retention.

The use of logistic regression was adopted to investigate whether national exam scores or secondary GPAs are better predictors of first-year retention in higher education [8]. High-stakes exams are entrance exams for higher education and are equivalent to national benchmark tests in South Africa. The study concluded by stating that school GPA predicts retention better in higher education compared to high-stakes national exams.

In another study, the authors assessed the performance of one deep learning algorithm and twenty supervised machine learning algorithms in predicting student retention [7]. All twenty-one algorithms were trained using the following variables: school accreditation, type of school, interest, average grades, gender, parent age, residence, parent salary, house area, parent's university attendance, and in-university retention. Random forest classifier, logistic regression CV, decision tree classifier, Nu support vector classifier (NuSVC), and linear support vector machine were amongst the twenty-one models used. Out of the twenty-one models used, the NuSVC algorithm emerged as the most effective machine learning method in predicting whether students would persist in their university enrolment or not.

Based on the literature reviewed, random forest and support vector machines were found to be the commonly used predictive models, mainly for classification tasks such as predicting whether a student will be retained (1) or not (0) in university. The most frequently used variables in predictive models for student retention mainly fell under two categories of student data: student demographics and academic performance. It is worth noting that all the models used predicted student retention on an individual student level rather than an institutional level. As a result, the types of educational data analytics used are limited to learning analytics.

3. Materials and Methods

In this study, the Knowledge Discovery in Databases (KDD) framework is adopted. The application of the KDD framework is widespread in the field of educational data mining and academic analytics research [6,19]. The KDD framework provides a structured approach, comprising various steps, to convert raw data into actionable insights [21]. At an abstract level, KDD is concerned with developing methods for making sense of data [23]. The primary challenge addressed by the KDD framework is the transformation of low-level data into other forms that may be more compact, more abstract (such as a model of the data generation process), or more useful (for instance, a predictive model for estimating the value of future cases).

This structured pathway facilitates the extraction of valuable patterns, trends, and knowledge from datasets, empowering informed decision making. The KDD framework encompasses a series of essential steps: (1) data collection and understanding, (2) data pre-processing and transformation, (3) modelling, and (4) evaluation (as illustrated in Figure 1).

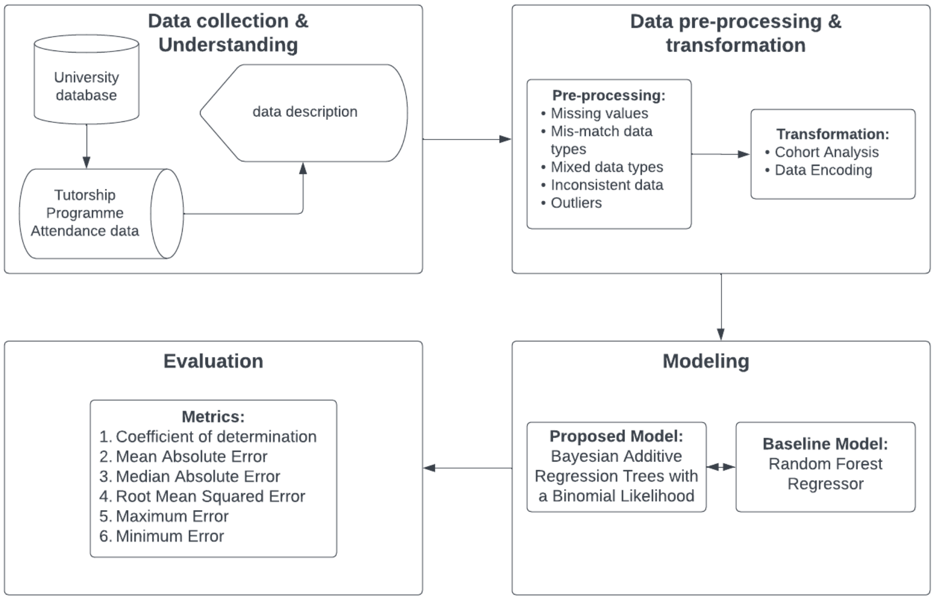

Figure 1. Knowledge Discovery in Database (KDD) framework.

3.1. Data Collection and Understanding

The tutorship programme attendance data, sourced from a South African university database, consisted of two central variables: tutorial date and encoded (anonymized) student numbers. These two variables played a crucial role in deriving other variables used to predict attendance-based retention in tutorial classes. The tutorial date variable captured the dates on which students attended tutorial classes, thereby enabling the establishment of attendance patterns and trends. Conversely, the encoded student number variable provided encoded identifiers for each student, ensuring the anonymity and privacy of students represented in the attendance data. These encoded student numbers were instrumental in tracking student retention over the course of the tutorship programme (Table 1).

Table 1. Tutorship programme attendance data.

Variable	Description
Tutorial date	Dates in which students attended tutorial classes.
Encoded student number	Anonymized student number of students. Each anonymized student number serves as a unique identifier for each student.

3.2. Data Preprocessing and Transformation

Data preprocessing and transformation is a key step that converts raw data into data that are more easily and effectively processed in models for more accurate and reliable results [6]. Firstly, data preprocessing was conducted to identify and handle missing data, mismatched data types, mixed data values, inconsistent data, and outliers. Secondly, data transformation was carried out through cohort analysis and data encoding. Cohort analysis is an analytical method that divides data into related groups called cohorts. These cohorts share a common characteristic within a defined timespan. In this study, cohorts were defined by the month in which students first started attending tutorial classes. The cohort analysis transformed tutorship attendance data to retention data. The transformed tutorship attendance data after cohort analysis consisted of 53 observations. Table 2 shows the description of variables derived from tutorial date, and encoded student numbers after cohort analysis.

Lastly, data encoding was applied to cohort and period as they were in date formats. The data encoding process involved transforming cohort and period into numeric formats that can be used as input in the modelling step.

Table 2. Descriptions of variables of interest.

Variable	Description
Cohort	The date students started attending tutorials.
Period	The date students stopped attending tutorials.
Cohort Age	The difference between period and cohort, in days.
Students	The number of students that started attending tutorials for a particular cohort.
Active Students	The number of students currently attending tutorials at a particular period.
Retention	The number of active students divided by the number of students.

3.3. Modelling

In this study, two models were implemented: the random forest regressor (RFR) and Bayesian addictive regression trees (BART). These models were implemented using historical tutorial attendance data to predict attendance-based retention in tutorial classes. The random forest regressor was selected as the benchmark model to enable a robust performance comparison against the Bayesian additive regression trees.

3.3.1. Random Forest Regressor

The RFR is a robust ensemble regression technique that leverages the combined power of multiple decision trees and employs a technique called bootstrapping and aggregation to improve predictive accuracy [24]. This technique provides several advantages, making it a valuable tool in modelling. From a computational perspective, the RFR offers several key strengths. It is known for its efficiency, as it is relatively fast both during the training phase and when making predictions. This speed is a result of its parallelizable nature, which allows for efficient implementation across high-dimensional datasets. The RFR depends on only one or two tuning parameters, which simplifies the modelling process. Additionally, it incorporates a built-in estimate of generalization error, aiding in the assessment of model performance and the prevention of overfitting [25].

The core principle of the RFR is to ensemble decision trees, combining their individual predictions to produce a more accurate and robust final output [26]. This is achieved through a process known as bootstrapping. When constructing the ensemble, the RFR algorithm repeatedly selects random samples with replacement from the original dataset. For each of these bootstrap samples, decision trees are trained to predict the response variables based on the corresponding features. Specifically, for each iteration b (where b ranges from 1 to B, the number of bootstrapped samples), a random sample is drawn with replacement from the dataset $(x,\ Y)$, yielding $(x_b,\ Y_b)$. A decision tree regression model denoted as f_b is then trained on this sample. After completing the training phase for all B decision trees, the RFR is ready to make predictions. When presented with a new data point $\acute{x}$, the ensemble regression model aggregates the predictions from all B individual decision trees to arrive at the final prediction. This aggregation is performed by calculating the average of the predictions made by each tree, represented as $\hat{f} = \frac{1}{B}\sum_{b=1}^{B} f_b(\acute{x})$.

The RFR's strength lies in its ability to reduce overfitting, improve model robustness, and enhance predictive accuracy through the combination of multiple decision trees [24,26]. The RFR model was constructed using the default RFR model parameters as specified by Sklearn.

3.3.2. Bayesian Additive Regression Trees

BART is a recent statistical approach that merges the principles of ensemble learning with nonparametric regression [27–29]. What distinguishes BART is its construction within a Bayesian approach, enabling the quantification of prediction uncertainty through a model-based approach [27–30]. BART's novelty lies in its capacity to adapt to complex relationships in the data while providing a robust and probabilistically grounded means of assessing predictive uncertainty, which sets it apart from traditional regression methods [29]. Mathematically, the BART model can be represented as follows:

$$\mathbb{E}[Y] = \phi\left(\sum_{j=0}^{m} g_j\left(X; T_j, M_j\right), \theta\right) \tag{4}$$

where X represents the model covariates (independent variables), each g_j is a tree of the form $g\left(X; T_j,\ M_j\right)$, where T_j represents the structure of a binary tree, i.e., the set of internal nodes and their associated decision rules and a set of terminal nodes. $M_j = \left\{\mu_{1,j},\ \mu_{2,j},\ \ldots, \mu_{b,j}\right\}$ represents the values at the b_j terminal nodes, ϕ represents an arbitrary probability distribution that will be used as the likelihood in the model, and θ represents other parameters not modelled as a sum of trees [21]. In this study, the BART model was specified as follows:

$$N_{active\ students} \sim Bin(N_{students}, p) \tag{5}$$

$$logit(p) = BART(cohort\ age, month) \tag{6}$$

where $Bin\ (N_{students},\ p)$ represents the likelihood probability distribution for the number of active students. This likelihood was used to indicate that the number of active students follows a binomial distribution. The selection of a binomial likelihood in the BART model was motivated by its suitability for count data, reflecting the act of counting active students within a group of students. Here, p represents the retention rate. In the BART model, the logit function given by $logit(p) = \log\left(\frac{p}{1-p}\right)$ was used as a transformation function to map retention rate in the range $(-\infty, +\infty)$ so that the range is not constrained to $(0, 1)$. The logit transformation allowed for a flexible and nonlinear estimation of log-odds of success, accounting for the complex interactions between cohort age and month. To interpret the results in terms of retention rate $(0, 1)$, the inverse logit function, $p = \frac{\exp(logit)}{(1+\exp(logit)}$, was used, where $logit$ represents the log-odds value. This transformation allowed the conversion of the model's log-odds back into the $(0, 1)$ range, enabling the estimation of a retention rate at a given time point.

3.3.3. Evaluation

The retention variable in tutorial classes was modelled as a continuous variable that ranges between 0 and 1, where 0 means that 0 percent of the students are retained in tutorial classes, while 1 means that 100 percent of the students are retained in tutorial classes. The retention prediction error was evaluated using six metrices that are commonly used for continuous variables, namely, minimum error, maximum error, mean absolute error (MAE), median absolute error (MedAE), root mean squared error (RMSE), and coefficient of determination. Each evaluation metric captures different aspects of model performance. By using all six of these metrics, a more comprehensive assessment of model performance was provided. This allowed the analysis of various facets such as the range of errors (minimum and maximum), average errors (MAE), robustness to outliers (MedAE), precision (RMSE), and the proportion of variance explained (coefficient of determination). In the error metric calculations, $\hat{y}_i$ represents the predicted value of the i-th sample and y_i is the corresponding true value.

4. Results

4.1. Descriptive Analysis

After applying the methods for data preprocessing and transformation described in Section 3, six variables were derived: "Cohort", "Period", "Cohort Age", "Students", "Active Students", and "Retention". Table 3 presents a comprehensive overview of key descriptive statistics for the six variables of interest. The "Cohort" and "Period" variables, representing the start and end dates of student attendance, do not have meaningful measures like means, medians, or standard deviations due to their date nature; however, they provide a range, with "Cohort" spanning from 1 January 2022 to 1 October 2022, and "Period" ranging from 1 March 2022 to 1 December 2022. "Cohort Age" has a mean of 141.62 days, indicating that, on average, students attended tutorials for this duration. The median of 122 days shows the typical duration, while a standard deviation of 85.69 days reflects some variation. On average, 183.60 "Students" are present in tutorial classes on any given day, with considerable variability (standard deviation of 155.08) between cohorts, ranging from a minimum of 10 to a maximum of 421 students. "Active Students" has an average of 50.87 and a median of 32, indicating the typical number of students actively participating, with significant variability (standard deviation of 65.17). "Retention" showcases an average retention rate of 33.34%, a typical rate of 24.23%, and a standard deviation of 28.54%, reflecting the diversity in how well students are retained, with rates ranging from a minimum of 0.45% to a maximum of 94.92%. These statistics provide valuable insights into the dynamics of student participation and retention in this study.

Table 3. Descriptive statistics of variables of interest.

Variable	Mean	Median	Standard Deviation	Max	Min
Cohort	-	-	-	1 October 2022	1 January 2022
Period	-	-	-	1 December 2022	1 March 2022
Cohort Age	141.6226	122	85.6869	344	28
Students	183.6038	80	155.0793	421	10
Active Students	50.8679	32	65.1652	263	1
Retention	33.34%	24.23%	28.54%	94.92%	0.45%

Figure 2 displays the variation in retention rates over time across nine different cohorts. Each cohort indicates the starting date of students attending tutorial classes. The retention rate is at its highest when students commence their tutorial classes and gradually decreases until June (2022-06) and July (2022-07), after which it increases again and then decreases towards November (2022-11) and December (2022-12). Notably, the June, July, November, and December period coincides with mid-year and end-year exams and the semester break, during which the retention rate is at its lowest, suggesting that students discontinue attending tutorial classes to focus on exam preparation, with a holiday break happening after. This illustrates a clear seasonality component in the retention, as depicted in Figure 2, where seasonality peaks decrease over time for each cohort of students.

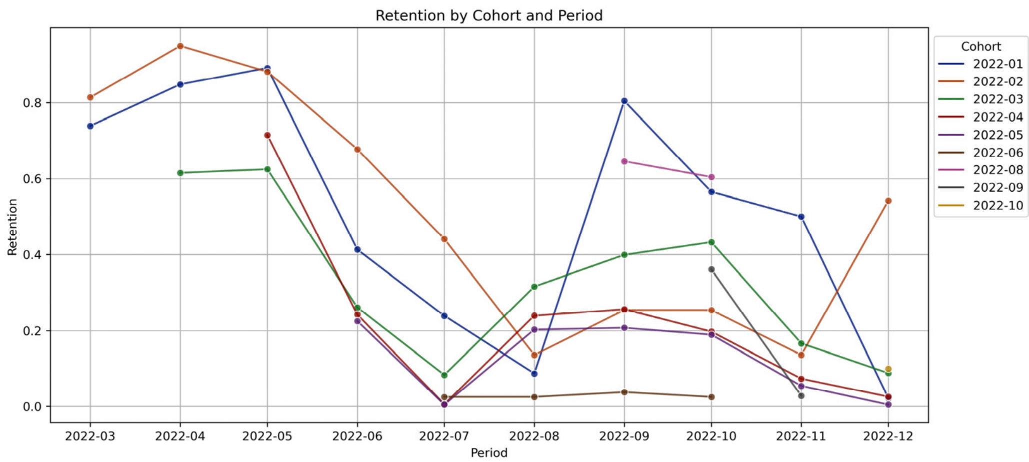

Figure 2. Retention by cohort and period.

4.2. Model Evaluation

The BART model with a binomial likelihood is assessed in comparison to the RFR using six key metrics: R-squared, MAE, RMSE, MedAE, Max Error, and Min Error. Student retention, ranging from 0% to 100%, serves as a critical indicator, representing the percentage of students retained in tutorial classes.

Table 4 displays the model evaluation results for BART with a binomial likelihood and the RFR model. BART demonstrates strong predictive capabilities, outperforming RFR across all key evaluation metrics, with a significantly higher R2 score of 0.9414 compared to RFR's 0.9150. This indicates that BART effectively captures a greater proportion of the variance in student retention. Additionally, BART yields a lower MAE of 4.75% as opposed to RFR's 6.66%, indicating more accurate predictions on average. The RMSE for BART (6.85%) is also lower than that of RFR (8.25%), signifying that its predictions are generally more precise. The MedAE of 3% for BART reflects its consistency in providing predictions close to the actual retention, while RFR shows an MedAE of 6%. Furthermore, BART achieves a slightly lower maximum error (19%) compared to RFR (20%). Both models exhibit a minimum error of 0%, indicating accurate predictions in some instances.

Table 4. BART and RFR model evaluation.

Model	R2 Score	MAE	RMSE	MedAE	Max Error	Min Error
BART	0.9414	4.75%	6.85%	3%	19%	0%
RFR	0.9150	6.66%	8.25%	6%	20%	0%

The BART model demonstrates stronger predictive capabilities in predicting student retention in tutorial classes as compared to RFR; this would make BART the preferred choice for educational institutions in need of robust predictive capabilities.

4.3. BART Model Highest Density Interval (HDI) Estimates

Figures 3 and 4 show the 94% HDI uncertainty estimates for a set of individual cohorts. The HDI is a range of values that captures a certain percentage of a model's parameters [21]. It provides a measure of the uncertainty in the parameter's value and can be used to make inferences about the parameter [21]. The 94% HDI in Figures 3 and 4 is a range that captures 94% of the posterior distribution of BART parameters. This means that there is a 94% probability that the true retention rate falls within this interval. A wide HDI interval is an indication of great uncertainty, while a narrow HDI interval is an indication of great certainty. Narrower HDIs indicate more reliable predictions as they suggest that the model has effectively minimized uncertainty. This precision leads to a higher level of confidence in the prediction, offering a more trustworthy basis for decision making. Precision in the context of HDIs refers to the narrowness of the interval that captures the range of plausible values for a prediction [12].

In Figures 3 and 4, the 94% HDI interval is wide for cohorts 2022-01, 2022-02, 2022-06, 2022-08, and 2022-09, indicating great uncertainty in the BART model's predictions for student retention in these cohorts. Conversely, the 94% interval is narrow for cohorts 2022-03, 2022-04, and 2022-05, indicating a great level of certainty and reliability in the BART model's predictions for student retention in these cohorts.

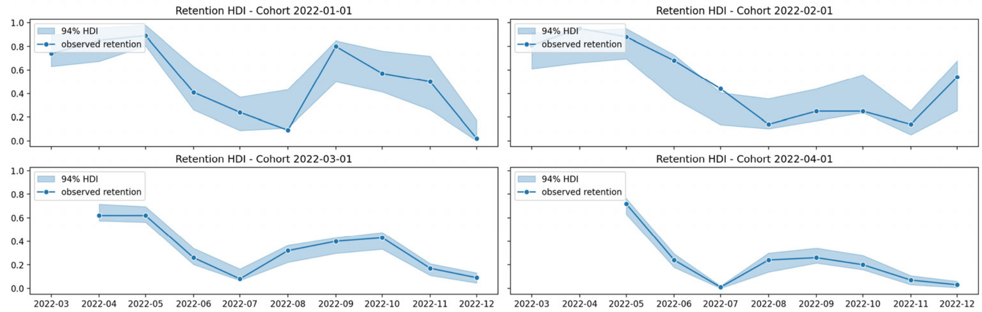

Figure 3. BART 94% HDI for 2022-01 to 2022-04 cohorts.

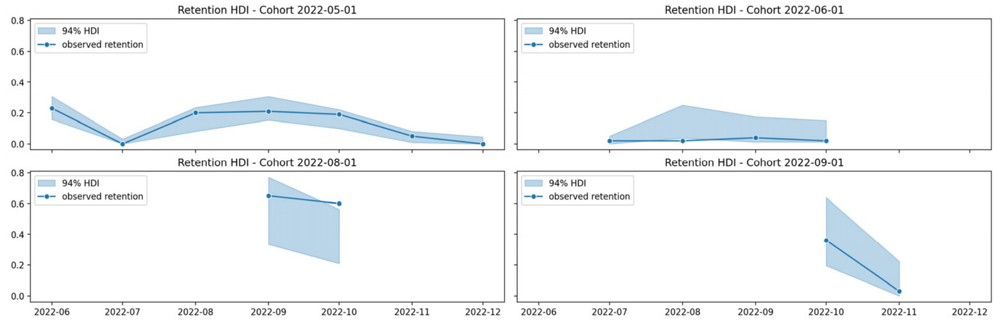

Figure 4. BART 94% HDI for 2022-05 to 2022-09 cohorts.

The high degree of certainty observed in cohorts 2022-03 to 2022-05, as evident by the 94% HDI closely aligning with the observed retention rate, underscores the BART model's accuracy in predicting student retentions from the onset of tutorials to just before the start of exams. For situations requiring a single prediction, the average or median of the predicted retention values within the 94% HDI can be used as a point estimate.

In practice, the BART model's computational demands ae notable due to its complex Bayesian framework and the intensive simulations required for tree-based modelling. This is particularly evident when handling large, high-dimensional datasets, where training times can be significantly longer [29]. While the model's strong predictive performance and ability to quantify uncertainty are valuable assets, these computational challenges must be considered. However, by employing strategies such as parallel processing and optimized algorithms, it is possible to mitigate these issues and enhance the model's feasibility for practical applications.

5. Conclusions

This paper introduces a BART model with a binomial likelihood for predicting student retention in tutorial classes within tutorship programmes. When compared to the random forest regressor (RFR), the BART model demonstrated an average improvement of 20% in predictive performance and achieved an R-squared score of 0.9414. This enhanced performance underscores BART's ability to adapt to nonlinear patterns in student data and its proficiency in quantifying prediction uncertainty, thereby supporting more informed decision making.

Tutorship support is one of many student support programmes within educational institutions. Future research could build on this study by exploring various machine learning and statistical models for predicting student retention across different support programmes, facilitating timely interventions. Incorporating a broader range of student data variables and applying interpretable machine learning techniques could also provide deeper insights into the factors influencing student retention in these programmes.

While the Bayesian approach is well established for quantifying uncertainty in model parameters and predictions, conformal prediction (CP) offers a complementary framework. CP is particularly effective at generating prediction regions that capture the inherent variability of point predictions, adding an essential layer of reliability to predictive modelling [31]. Integrating CP with student retention models could further enhance the precision and reliability of predictions.

This study's findings hold significant relevance for various stakeholders in the educational ecosystem. Educational institutions, administrators, and policymakers can gain valuable insights into predicting student retention rates in tutorship programmes. This information can aid in developing tailored intervention strategies to improve student retention. For instance, tutorship programme coordinators can utilize these predictive models to identify periods of low or high retention and implement timely interventions to foster student engagement. Furthermore, the foresight provided by expected student retention rates can assist in strategic resource allocation, leading to more informed planning and budgeting for support programmes.

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education sciences

Article

An Innovative STEAM-Based Method for Teaching Cycloidal Curves in Engineering Higher Education

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Abstract: Robotics offers innovative possibilities at all levels of education, which should be considered when planning the teaching process for certain engineering mathematics topics in higher education. This paper introduces a new teaching–learning technique that utilizes STEAM-based methods to explore cycloidal curves for Computer Science Engineering BSc students. Traditional frontal teaching has been enhanced with methods addressing the generational needs of students, including problem-based learning, STEAM integration, and project-based learning. We developed a methodological model that merges traditional teaching advantages with practical modern approaches suitable for Generation Z. The four-stage model for learning cycloidal curves employs various didactical approaches, utilizing different learning techniques at each stage to create an engaging and effective learning experience. A vital component of this model is the use of Desmos dynamic geometry software to create animations alongside educational robotics to aid visualization. We conducted quantitative studies with 98 first-year Computer Science Engineering students using a quasi-experimental research design to evaluate the new teaching technique's effectiveness. Results from the Mann–Whitney U test indicated that the experimental group significantly outperformed the control group. Additionally, the Kruskal–Wallis test confirmed that the four-stage model for learning cycloidal curves enhances learning achievement for all students, regardless of their prior knowledge.

Keywords: engineering mathematics; cycloidal curves; dynamic geometry software; central trochoids; project-based learning; LEGO 4C learning model; educational robotics

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1. Introduction

Understanding scientific and mathematical knowledge and practices, as well as technological and engineering practices, has become a priority for national education programs across the world [1]. STEAM (Science, Technology, Engineering, Art, Mathematics) has recently become a standard part of higher education internationally, with many universities adapting their curriculum to integrate it [2]. STEAM is the evolution of STEM (Science, Technology, Engineering, Mathematics), which was first introduced by the US National Science Foundation (NSF) in the 1990's [3]. STEM was initially developed to address the ongoing low performance of students from the Western world in mathematics and science in international assessments and to encourage students to pursue careers in these fields [3]. In 2010, Bybee [4] called for quality science education that includes technology and engineering: *"A true STEM education should increase students' understanding of how things work and improve their use of technologies. … Engineering is directly involved in problem-solving and innovation, two themes with high priorities on every nation's agenda … the creation of high-quality, integrated instruction and materials, as well as the placement of problems associated with grand challenges of society at the centre of study"*. The extension of STEM to STEAM was first proposed in 2013 [5]. As the name STEAM suggests, there is a crucial focus on encouraging students to think in a broader perspective than that of each individual subject [6]. STEAM has been shown to improve conceptual and deep understanding of the subjects covered.

Kang [7] in 2019 conducted a literature review of 6 studies, which included analyzing 256 papers from schools that provide STEAM education, and the results demonstrated that there is a positive and immediate effect on the student's conceptual understanding. The methods of STEAM education are now widely used and applied at all levels of education, including higher education.

1.1. What Is Engineering Mathematics?

Engineering mathematics has two distinct but interconnected facets. On one hand, it serves as the foundation for engineering programs and is typically taught by mathematicians. On the other hand, mathematics is an integral component of engineering science, providing the tools and framework for understanding and solving complex problems [8]. Over the past decade, advancements in technology have significantly impacted the field. New algorithms and methods have emerged to help engineers analyze large databases, build predictive models, and solve optimization problems [9]. The increasing power of computers has enabled the application of complex numerical methods and simulation techniques, supporting engineers in modeling and understanding intricate physical phenomena such as fluid dynamics, structural analysis, and electromagnetic design [10–12]. While still in its early stages, quantum computing offers immense potential to further revolutionize engineering mathematics [14**?**]. We can expect breakthroughs in complex optimization problems and simulations, potentially influencing engineering design and research [15]. These innovations and methods empower engineers to work more efficiently on technical challenges and open new opportunities for developing and applying technology.

Engineering students' training in mathematics is a top priority. The field relies heavily on mathematical principles, with foundational subjects like calculus, differential equations, linear algebra, and statistics being crucial for understanding and solving engineering problems. A robust mathematical background equips engineers with critical thinking and problem-solving skills, enabling them to design systems, troubleshoot issues, and optimize processes [15,16]. As modern engineering increasingly leverages sophisticated technology, a deep understanding of advanced mathematical algorithms becomes essential [17]. Fields like artificial intelligence (AI) and machine learning (ML) require extensive knowledge of linear algebra, calculus, and probability [18]. Engineering innovation and research continually push the boundaries of mathematical knowledge, necessitating that engineers working on cutting-edge technologies, such as quantum computing or advanced materials, possess a comprehensive understanding of both applied and theoretical mathematics [19,20]. Ultimately, mathematics is the foundation upon which engineering principles are built, equipping students with the skills to solve complex problems, innovate, and excel in a technologically advanced and interdisciplinary world. Teaching mathematics to engineers in higher education requires a thoughtful and well-structured approach to meet the needs of the profession and prepare students for the future challenges they will face [8,21].

Engineering mathematics education should provide a strong foundation in core subjects, demonstrating theoretical concepts through practical examples that showcase their real-world applications in engineering problem-solving. Rogovchenko and Rogovchenko [22] argued that mathematical modeling projects can effectively develop students' mathematical competency, enhance their understanding of engineering concepts, and improve their communication and collaboration skills. They provide a specific project example in their work, concluding that such projects are crucial for developing the necessary skills for engineering success. Education should embrace modern software and technologies [23], using computer simulations to reinforce theoretical knowledge and provide students with practical experience. Integrating project-based learning (PjBL) is essential, as it allows students to engage in significant projects and real-life case studies, enhancing their problem-solving and analytical skills. Interactive classrooms, where students are actively encouraged to participate in solving problems and understanding concepts [24], foster a more dynamic and engaging learning environment. The curriculum must adapt to technological advancements, equipping students with the knowledge and skills to effectively utilize new educational technologies to maximize their learning and prepare them for continuous professional development [25].

1.2. STEAM-Based Education and Educational Robotics

Technology and innovation play an increasingly important role in modern life, and education must evolve based on innovation and technological progress to keep pace with a changing world. Digital technologies have made a paradigm shift in the entire education system [25]. STEAM-based education is gaining increasing prominence at universities [26], which is particularly important for engineering higher education. Today's university students increasingly demand educational methods that they find engaging, relevant, and interactive. STEAM education offers a dynamic and attractive learning experience [27]. Many contemporary challenges are complex and multidisciplinary. The STEAM approach allows university students to combine knowledge from various scientific and artistic fields to understand and address these challenges. The spread of problem-based learning is a consequence of the realization that learners are left with minimal knowledge after learning through traditional, frontal teaching methods and find it difficult to apply the knowledge they acquire in other contexts. Problem-based learning provides a learning environment where learners can use and reinforce prior knowledge, learn in real-life contexts, and develop their knowledge in individual or small group work [28]. Developments over the past decade have led to the availability of a wide range of robotic learning tools, all with the common goal of innovation and motivating learners in the learning process.

Robotics and computational thinking are valuable tools for developing STEAM pedagogy and promoting the inclusion and integration of diverse groups of students. There are many robotic teaching tools at our disposal intended to encourage innovation and motivation of students during the learning process. As robots are increasingly common in our world, it is essential to integrate them into education [29,30]. Robots have clearly opened up new possibilities in teaching and learning. Educational robotics (ER), which involves robotic techniques in education, is seen as a groundbreaking learning tool that enhances the learning environment, transforms teaching and learning methods, and fosters a new educational ecosystem [31]. Of course, most of the educational applications of ER focus on robotics-related subjects such as robot programming, robot building, and artificial intelligence [32–34].

LEGO Education focused on STEM-based learning from the beginning, even before this acronym was standard [35,36]. The collaboration with MIT has played a crucial role in developing LEGO's robotics products. LOGO is a programming language developed in the 1960s at MIT, designed to make coding accessible for children. Its most famous feature is the turtle, a simple robot or on-screen graphic controlled with commands, teaching basic programming concepts like sequencing and loops [37]. In the mid-1980s, the LOGO research group began collaborating with the LEGO group because LEGO Group recognized the potential of teaching and learning with robots [35]. The partnership between LOGO and LEGO brought programming to life, starting with LEGO/LOGO, which combined LEGO building with LOGO code. The history of LEGO robots dates back to the end of the 20th century when the LEGO Group started developing robotic kits. The first significant step was introducing the LEGO Technic series in the late 1970s, which allowed users to build more complex mechanical models. The programmable brick revolutionized the process by allowing LEGO creations to be independent and mobile, paving the way for LEGO Mindstorms [38]. Various generations of LEGO robotics kits have been released in the last twenty years: Mindstorms NXT in 2006, NXT 2.0 in 2009, and Mindstorms EV3 in 2013. Souza et al. [33] conducted a systematic review of the literature analyzing the use of LEGO robotics technology as an instrument for teaching, considering the robotics kits and their programming environments as a combination of teaching methodologies and practices. In 2018, it was reported that the most commonly used environment and programming languages are LabVIEW and LEGO's block-based programming language. Additionally, Souza et al. [33] found that LEGO Robotics is utilized for teaching programming, interdisciplinary subjects, participating in tournaments, robotics, and computational thinking. Furthermore, LEGO® Robotics has been successfully used by students across various levels, including K-12, undergraduate, and graduate programs. The most recent product in the evolution of LEGO robots, SPIKE Prime, was released in 2020 and is already very popular [39]. One reason for this is probably that the robot can be programmed in several ways, and one option is the Scratch programming language [35]. Ersozlu et al. [40] used a scientometrics analysis to map data from the scientific literature based on different kinds of published research and found that computational thinking (CT) in mathematics education was mostly about teaching computational skills and computer programming through practical and algorithmic thinking in engineering and STEM education, especially at the higher education level. In addition, Scratch has been the dominant tool used to teach programming skills at all levels of schooling, including higher education.

Educational robotics has been successfully used for many years as a tool to make learning more experiential and effective [41]. Combining educational robotics with problem-based learning is not a new idea, and educational software developed for LEGO Education robot kits (WeDo 2.0, EV3, SPIKE Prime, SPIKE Essential) includes learning projects that essentially implement problem-based learning as an integral part of the design of the educational software [35]. However, these projects focus on basic physical, biological, and social science knowledge and learning robot programming concepts [42]. In order to target STEAM-based methodology in higher education, it is necessary to develop new robot constructs and build student projects around them.

Despite the potential of integrating robotics into teaching and learning, this integration has not yet been fully explored in university practice, especially in higher mathematics education.

1.3. Importance and Teaching of Cycloidal Curves

Roulette is a path traced by the point fixed on a curve that is rolling on another fixed curve [43]. Cycloidal curves are a family of roulettes generated by the motion of a point attached to a circle as the circle rolls along a fixed straight line or another circle. These curves include trochoids, epitrochoids, and hypotrochoids, as shown in Table 1.

Table 1. Classification of cycloidal curves.

	Cycloidal Curves (A Circle Rolling on Another Circle or a Line)		
	Epitrochoids (A Circle Rolling Outside Another Circle)	**Trochoids (A Circle Rolling on a Line)**	**Hypotrochoids (A Circle Rolling Inside Another Circle)**
The tracing point is on the circumference of the moving circle	Epicycloid	Cycloid	Hypocycloid
The tracing point is inside the moving circle	Curtate epitrochoid	Curtate cycloid	Curtate hypotrochoid
The tracing point is outside the moving circle	Prolate epitrochoid	Prolate cycloid	Prolate hypotrochoid

The parametric equations and graphs of the cycloidal curves are given in Appendix A. We note that the term central trochoid encompasses both epitrochoids and hypotrochoids [44]. The center of a central trochoid curve is defined as the center of the fixed circle.

In engineering mathematics, theory and application go hand in hand. Cycloidal curves are very useful in practical life. In 1694, Philip de la Hire published a complete mathematical analysis of epicycloids and recommended an involute curve for designing gear teeth. However, in practice, it was not used for another 150 years. In 1733, Charles Camus expanded la Hire's work and developed theories of mechanisms. Twenty years later, in 1754, Leonard Euler worked out design principles for involute gearing. Felix Wankel developed the Wankel Rotary Engine in the 1920s. Initially developed as an air compressor, the engine is now used in automobiles. The rotor is an equilateral triangle with curved sides, and the bore is an epitrochoid curve. Nowadays, epitrochoids can be found in important mechanical parts such as gears with epitrochoid tooth profiles, cams, and epitrochoid-shaped housings for rotary internal combustion engines and rotary piston pumps. For the last case, the epitrochoid curve notes the path that the rotor tip of the eccentric shaft traces out upon revolving [45]. Hypocycloid curves also have many important applications in engineering. One of these is the use of the astroid shape in the process of moving bus doors [46]. In addition, central epi- and hypotrochoids can be used, for example, in surveillance or spatial coverage applications, as periodic motion primitives for human dancers or for performing complex choreographic patterns in small autonomous vehicles [47], as well as in the context of autonomous robot navigation with collision-free and decoupled multi-robot path planning [48]. Cycloidal curves are used in roller coaster design, architecture (Kimbell Art Museum, Hopkins Center for the Arts), and the creation of geometric patterns for stained glass windows, mosaics, and textiles [49].

The wide range of applications above shows that cycloidal curves represent fundamental mathematical and geometric concepts indispensable in various engineering fields. In his 1913 article, Epsteen [50] summarized the minimum content to be taught in engineering mathematics, emphasizing the importance of higher plane curves in the curriculum, including cycloids, hypocycloids, and epicycloids. These curves are extremely important for mathematical foundations because the knowledge associated with them becomes relevant in the context of kinematic analysis and mechanical design. Cycloidal curves help engineering students better understand motion and force transfer principles, especially in mechanical systems [51]. By studying such curves, students learn the precise design and efficient calculations that are essential for a variety of engineering applications. In addition, the presentation of cycloidal curves is also important in modeling the behavior of physical motions, such as the behavior of a pendulum [52]. In modern computer-aided design programs, the accurate representation of cycloidal curves allows the efficient design of complex mechanical components. Cycloidal curves are not only mathematical curiosities but also fundamental tools for solving engineering problems.

In university engineering mathematics education, cycloidal curves were taught in the 18th and 19th centuries using geometric and analytical methods. Students usually learned from hand-drawn diagrams and understood mathematical equations involved in on-the-spot demonstrations and geometric proofs [53,54]. Kinematic models and mechanical devices were used for illustration because the derivation of the equations of cycloidal curves and the representation requires visualization [55]. Several of these constructions are included in Schilling's famous collection of kinematic models [56]. Kinematics, which involves the study of motion, played an important role in understanding cycloidal curves, especially in analyzing mechanical systems and motions. The emphasis was on geometric insights and classical physical examples. Traditional teaching methods for students at universities are outdated and not effective enough [52]. In today's education, modern technologies and computer simulations are now used to help understand the knowledge of cycloidal curves. Several didactical articles deal with visualizing cycloidal curves using dynamic geometric software or simulation embedded in a remote experiment [52,57,58]. These methods have many advantages in terms of visualization, but they do not provide direct experimental experience. The recent research of Tessema et al. [59] highlights the importance of a realistic, hands-on approach to learning in mathematics education, particularly in the study of geometry. Traditionally, drawing cycloidal curves is a lengthy process that requires engineering drawing knowledge. A simpler and faster way to produce curves is to have a robot draw the curve during an ER activity. By building and then testing the drawing robots, students gain first-hand experiences [60–64].

1.4. 4C Learning Approach

LEGO's philosophy is that effective learning can only be achieved through a holistic approach because learning has creative, cognitive, social and emotional aspects. The LEGO 4C principle is a pedagogical model developed by LEGO Education, focusing on four fundamental key competencies in learning [65]. The LEGO 4C learning approach is characterized by its hands-on, inquiry-based, and collaborative nature, which aligns with constructivist and experiential learning theories. It engages students in active learning experiences where they actively construct knowledge, explore concepts, and solve problems.

By integrating the four Cs into educational activities, the LEGO 4C learning approach aims to foster creativity, critical thinking, collaboration, and communication skills in students, preparing them for success in the 21st century [66]. These key competencies are as follows:

- Connect: This first C stands for connection, meaning establishing a connection. Students should be given the opportunity to connect with the subject matter and recognize its relevant and interesting context. This allows learning to more closely align with students' everyday lives and experiences.
- Construct: The second C stands for construction, which means allowing students to create or build something. This could be a physical model, a project work, or a digital creation. The act of constructing enables students to deepen and apply their learning.
- Contemplate: The third C stands for contemplate, which encourages students to reflect on the things they have created and what they have learned. This includes reflection and self-reflection, as well as critical evaluation of the application of what they have learned.
- Continue: The final C stands for continue, which means giving students the opportunity to further develop, apply, and share what they have learned and created with others. This process can help sustain learning and apply what has been learned in practical ways.

These four phases are steps in an iterative process that should often be seen as a learning spiral (Figure 1); the four links are not a single linear structure but a process of interlocking and dynamic circulation [66]. The LEGO 4C principle is a framework applied to learning and teaching that helps students establish a closer connection with the subject matter and apply experiential and hands-on learning methods. This allows for a deeper understanding of learning and enriches the learning experience.

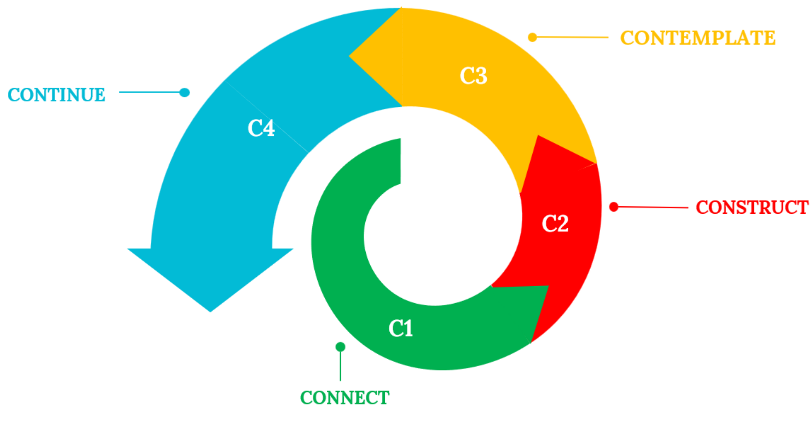

Figure 1. The LEGO 4C methodological spiral. (The figure was created using Microsoft PowerPoint).

The LEGO 4C methodology has mainly gained ground in primary and secondary education [65]. The 4C principle can also be applied in higher education because of the generational shift. We propose a methodological model based on the 4C principle to process the curriculum on cycloidal curves. Engineering students naturally show a keen interest in robotics and ICT tools, which aligns with their chosen specialization. To help them discover the secrets of cycloidal curves, we have developed a methodology combining frontal teaching with problem-based learning, educational robotics, and dynamic geometric software in project-based learning.

1.5. The Four-Stage Methodological Model for Learning Cycloidal Curves

The first element of the four-stage model for learning cycloidal curves is frontal teaching (lecture and practice), where the theoretical material is presented, covering cycloidal curves (Figure 2). In fact, many studies have been carried out over the last two decades on the disadvantages of frontal teaching. However, it is still the dominant teaching method in higher education [67]. Ganyaupfu [68] investigated that the teacher–student interactive method was the most effective teaching method over the teacher-centered approach because direct teaching is efficient in transferring knowledge but is not sufficient for deeper understanding, problem-solving, and creativity. Innovative teaching incorporates technology into the teaching–learning process to create a rich and helpful learning experience for students and a rewarding teaching experience for teachers [69,70]. It should not necessarily be abandoned for large courses and frontal teaching, but it should be complemented by techniques where students are not passive participants. There is evidence that lectures can effectively and structurally communicate information, model reasoning, and motivate students, particularly when adequately supported by other activities [71].

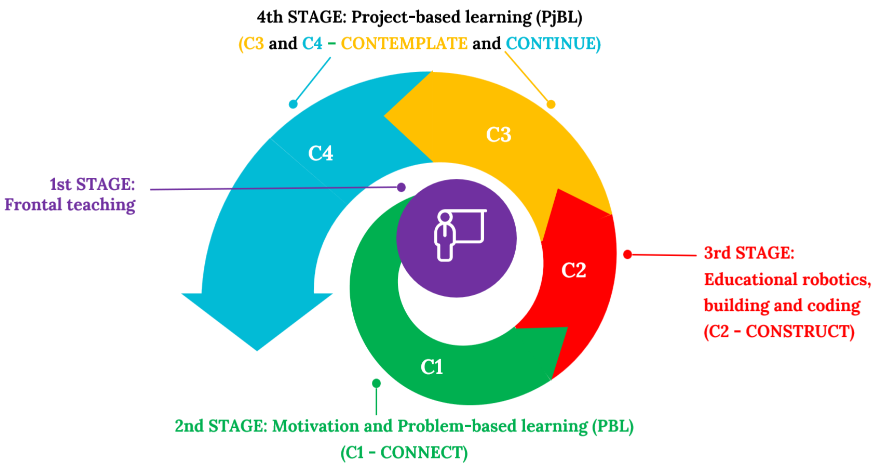

Figure 2. Scheme of the four-stage methodological model for learning cycloidal curves. (The figure was created using Microsoft PowerPoint 2021).

After the theoretical grounding, the topic of plane curves can be continued in specialized seminars. The second stage is to start working according to the 4C principle. The problem statement explores the possibility of producing a curve experimentally. We note that seminars are extracurricular activities. In the second phase, the focus is on attracting attention and motivation. Where possible, we choose demonstration experiments that students can carry out in small groups, documenting them and allowing them to gain direct experience. Problem-based learning (PBL) is achieved through the formulation of real-life tasks. Given that Connect aims to revive knowledge related to what has been learned previously, students are actively involved in solving the problems formulated. It is worthwhile to revive the most important theoretical knowledge; for this purpose, visualization solutions and animations can be used to illustrate cycloidal plane curves.

The third stage uses STEAM-based methods, i.e., building and programming drawing robots, and understanding how robots work. The educational robot kits allow students to explore a curve under investigation in small group activities. Working with robots requires providing building instructions for appropriate drawing robot designs and sharing conditions for working with robots. For four years, the authors have been designing drawing robots whose operating mechanisms can be mathematically deduced with precision. Using the LEGO Education SPIKE Prime robot set, educational robots have been designed to produce a wide range of representatives of the cycloidal curve family.

In Spirograph-like robot models, gears are used to model the circles that generate the cycloidal curves. The aim of [60] was to introduce the hypotrochoid family of curves and to give ideas and tools for teaching the topic. The general parametric equations of hypotrochoids were given, and several special curves that can be derived from these equations were shown. In addition, a drawing robot called Spikograph 1.0 (see Figure 3), modeled on a Spirograph toy, was presented, which can draw different hypotrochoids, giving students a physical experience. This robot uses LEGO gears to model the slip-free rolling of the circles, and knowing the gears' sizes, the parametric equations of the drawn curves can be easily written.

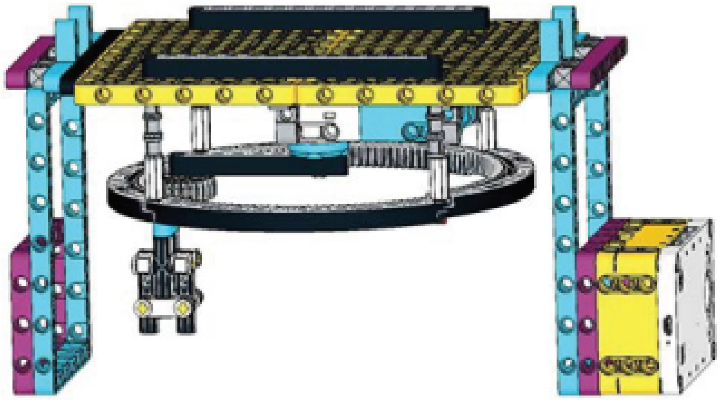

Figure 3. Spikograph 1.0 drawing robot. (The figure was created using Studio 2.0 software).

Spikograph 1.0 gave the idea to design Spikograph 2.0 (Figure 4) for drawing epitrochoid curves; this drawing robot was presented in [61]. The factor that most determines which epitrochoids can be drawn with the robot is the size of the suitable gears in the LEGO Education SPIKE Prime set. The diameters of the circles that define the epitrochoid correspond to the rolling diameters of the gears that model them. The rolling diameter of a gear is the diameter of an idealized disc that allows it to roll on the equivalent idealized disc of another gear that is usually meshing with it. This dimension is easy to determine since the rolling diameter of any LEGO gear, expressed in mm, is equal to the number of teeth on it.

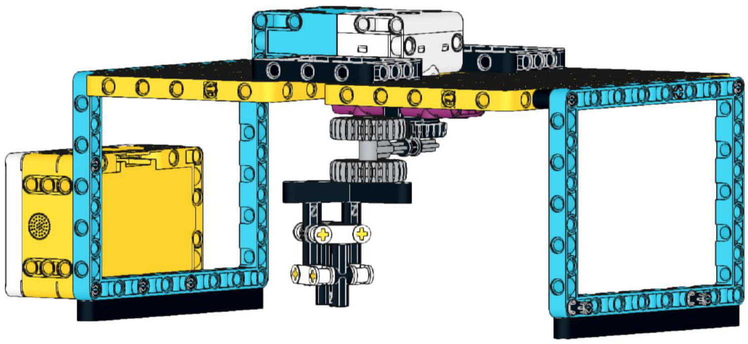

Figure 4. Spikograph 2.0 drawing robot. (The figure was created using Studio 2.0 software).

Students can work not only with these two gearing robots in the seminars. Although Spirograph-like robots are an excellent way to illustrate the production of many notable plane curves, the principle of operation of robots in the industry follows a different path. It is important that students can work through real-life tasks on various projects; therefore, the use of a SCARA-style robot design is also possible in the seminar series (see Figure 5). The SCARA robot is one of the common types of industrial robots [72]. The SCARA name stands for Selective Compliance Articulated Robot Arm. The main feature of the

SCARA robot is that it has a jointed 2-link arm driven by two independent motors [73]. It is well-known that the plots generated by a Spirograph toy can also be drawn using a 2-link planar or SCARA robot after computing the inverse kinematics to get the joint angles needed to perform the correct movements. It is also a known fact that the Spirograph toy is not able to draw all types of trochoidal curves; only the curtate types can be created. However, Spirograph-like and SCARA-style robots can draw all three types of central trochoids [63,64].

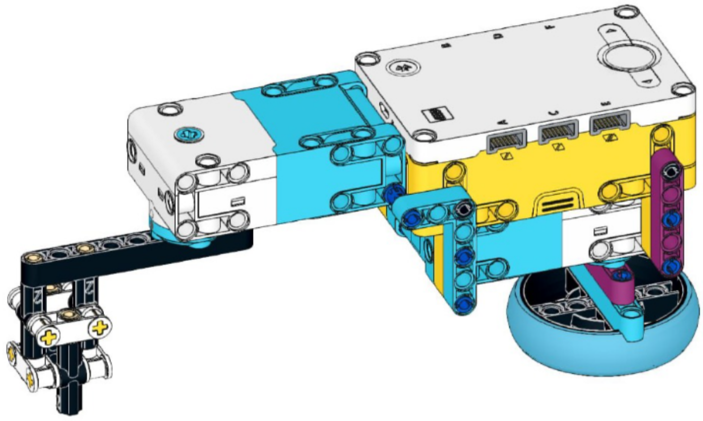

Figure 5. SCARA-style LEGO robot. (The figure was created using Studio 2.0 software).

Thanks to their construction, robots can draw an infinite number of cycloidal curves. However, the number of curves that can be drawn in the Spirograph toy is finite. Table 2 summarizes the central trochoids that can be drawn with the Spirograph, only LEGO gears and racks [74], and the various educational LEGO drawing robots. The SCARA-style robot can be used to draw all types of central trochoids, but its principle of operation does not follow the usual definition of curve generation. A big advantage of the robot versions using gears is that the generation of curves is based on the definition. Exploring the potential of drawing robots and how to integrate them into the educational process is an ongoing process of active research.

Table 2. Drawing central trochoids with didactic tools.

	Central Trochoid Curves (A Circle Rolling on Another Circle)					
	Epitrochoids			**Hypotrochoids**		
	Curtate	**Epicycloid**	**Prolate**	**Curtate**	**Hypocycloid**	**Prolate**
Spirograph toy	Yes	No	No	Yes	No	No
LEGO gears, racks	Yes	No	No	Yes	No	No
Spikograph 1.0 robot	No	No	No	Yes	Yes	Yes
Spikograph 2.0 robot	Yes	Yes	Yes	No	No	No
SCARA-style robot	Yes	Yes	Yes	Yes	Yes	Yes

The construction phase of the 4C principle is where the robot is built and programmed. Writing the program is also considered design because the robot can only operate with the right program. With Spirograph-like robots, this refers to the operation of a single motor, whereas with a SCARA-style robot, it refers to the coordinated operation of two motors.

The LEGO SPIKE Prime robot hub can be programmed in three ways, one of which includes the Scratch programming language. Developed by Mitchel Resnick at the MIT Media Lab, Scratch is an evolution of the LOGO language. This visual, block-based coding language features a drag-and-drop interface, making programming accessible and enjoyable for users [35]. Programs for drawing robots are created in Scratch using the original software designed for the LEGO SPIKE Prime robot.

In the contemplate phase, the synthesis is given through the solution of a project task, where the task is to create an animation modeling the robot's working principle. Students can work on the project independently or in groups, allowing for exchange and knowledge sharing. Project-based learning (PjBL) can be a very effective way to learn mathematics. PjBL involves students working on complex, real-life problems that require them to apply mathematical knowledge and skills. This approach helps students link theoretical knowledge with practical applications and develops their problem-solving and collaboration skills [75]. In project-based learning, it is important that the projects are genuinely interesting and relevant to the students and that they solve real problems [76]. The teacher has a key role to play in guiding and supporting students through the projects and helping them to understand the relationships and mathematical principles. Projects can also help students to see how mathematics relates to their everyday lives and to solve real-world problems. Relevant literature suggests that the link between PjBL and dynamic geometric software (DGS) is extremely useful in mathematics education [77,78]. DGS refers to computer software that allows the visualization and manipulation of functions, curves, and geometric shapes. This software can help students understand and visualize mathematical concepts that they can apply in PjBL projects. With DGS, students can see geometric constructions and shapes in real time, resulting in a visual understanding that supports students in handling abstract mathematical concepts better. The DGS provides an interactive platform through which students can experiment and modify geometric constructions on their own, significantly contributing to the development of active learning and an experimental approach. The link between theoretical and practical aspects is greatly facilitated by using DGS, as students can immediately see how functions, geometric shapes, and relationships change when they change parameters or manipulate constructs. Experiences have shown that the combined use of PjBL and DGS helps make mathematics teaching more interactive and understandable [78–80]. Students will be able to apply the mathematical knowledge they have acquired through DGS in real projects and will be able to combine theoretical and practical aspects more easily.

In the fourth stage of 4C, additional project tasks are connected to the studied curve. It is recommended that homework be solved using DGS. There are different types and versions of DGS. One of the most commonly used DGS is GeoGebra [79]. The application can be used for geometric and algebraic analysis. It offers several tools for visualizing functions, drawing and manipulating geometric shapes, and understanding mathematical concepts [80]. Desmos was originally a graphing calculator application but has since been extended to include DGS functionality. Desmos is a compelling application for visualizing functions and curves and helping to understand mathematical expressions [81], so it is worth using this DGS for engineering mathematics courses. Another advantage is that Desmos is also an excellent tool for project-based learning. Real-time graphs, data visualization, and interactive shape generation help students present their projects clearly and interestingly and provide opportunities for collaboration and interaction between students. For example, several students can collaborate on a project and see each other's work in real-time. In Desmos, students can animate graphs, which can help them better understand mathematical relationships and changes [82].

A well-designed methodology helps to structure and manage the learning process. It sets out the expected goals and outcomes for learners and the steps to be followed to achieve them. Based on the 4C principle, the four-stage methodological model for learning cycloidal curves considers learners' individual needs, interests, and abilities. It provides a flexible structure for differentiated learning experiences to ensure all students succeed. This method creates a motivating and engaging learning environment. Students enjoy learning through exciting and challenging tasks, contributing to long-term engagement and success.

Using the four-stage model for learning cycloidal curves, ellipses, cycloids, cardioids, astroids, and roses were discussed. The application of the four-stage model for learning cycloidal curves is illustrated in Appendix B with the example of teaching cardioid.

2. Materials and Methods

2.1. General Background

Many good practices are related to teaching 2-dimensional plane curves, including cycloidal curves, where the teaching model supports knowledge development through different visualization techniques. However, no methodological model was found on cycloidal curves, where STEAM-based education is integrated consistently into university practice. The need for this development and research was motivated by the fact that central trochoids are the most crucial two-dimensional plane geometric patterns widely used in real-life practice (see Section 1.3); however, alternative methods for teaching them in higher education were not available to provide students with first-hand experiences.

A new learning structure was created after a thorough study of the literature in the framework of Lithuanian–Hungarian cooperation. The new methodological model, the four-stage methodology for learning cycloidal curves (see Section 1.5), considers generational needs while making optimal use of the University of Miskolc's available infrastructure because the University of Miskolc training center has 24 LEGO Education SPIKE Prime educational robotics kits. The development started in May 2023. Researchers from the Šiauliai State Institute of Higher Education and the University of Miskolc jointly worked. Based on the previous experience [62], the researcher team compiled the additional teaching material needed to apply the new methodological model according to the 4C principle (Section 1.4). We have rethought the drawing robots' construction and created building guides with the seminar material. We sorted the problems related to cycloidal curves and selected them thematically for the seminars. The complete development of the four-stage methodological model for teaching cycloidal curves took half a year.

A methodology model is well-designed if it is based on scientific research and pedagogical principles. The four-stage methodology model for learning cycloidal curves is based on the 4C principle, which is the result of research conducted by LEGO Education and is, therefore, scientifically sound. In order to make the same claim about the overall structure, measurements have been carried out in the spring semester of the academic year 2023/24 to provide empirical evidence of the effectiveness of the four-stage model for learning cycloidal curves. The experiment was carried out in Miskolc, Northern Hungary. The research presented in this article continues the Lithuanian–Hungarian research conducted between June 2021 and June 2023 with 27 students at the University of Miskolc. The previous research focused only on a new, innovative approach to teaching the cardioid curve [62].

2.2. Research Design

This study used exploratory research, a quasi-experimental research design, and quantitative observation to assess the impact of the four-stage model for learning cycloidal curves. The quasi-experimental approach was necessary because it was impossible to randomly assign computer science engineering students to the experimental and control groups. The experiment was carried out in connection with the Calculus II course.

In the first part of this study, we used a post-test-only design. In the spring semester, the cycloidal curve topic is the first part of the Calculus II syllabus. All students who took the Calculus II course were absolved of the Calculus I course in the autumn semester, so all participants had a basic knowledge of the topic of engineering mathematics. A control group study was conducted, in which the experimental group learned using the four-stage model for learning cycloidal curves, while the control group was taught in a traditional format. The control group participated solely in traditional frontal lectures and practical lessons, whereas the experimental group benefited moreover from additional activities based on the four-stage model for learning cycloidal curves. The post-test-only design allows for a clear comparison between the intervention and control groups, helping to isolate the effect of the treatment. Table 3 summarizes activities during the Calculus II course.

Table 3. Activities during the Calculus II course.

	Cycloidal Curves				
	Frontal Teaching (Stage 1)		Other Activities (Stage 2 and Stage 3)		(Stage 4)
Topic	Lectures	Practical Sessions	R-STEAM Seminars	In-Class DGS Tasks	Homework Projects
	(Academic Hours)			(Exercises)	
Circles, ellipses	3	2	2	2	4
Trochoids	3	2	2	2	3
Epitrochoids	2	1	2	3	2
Cardioid	1	1	2	2	2
Hypotrochoids	2	1	2	3	2
Astroid	1	1	2	2	2

In the second part of this study, a between-groups design was used. This framework allows the effectiveness of the intervention to be assessed across different groups of participants. Based on their prior knowledge, the experimental group was divided into three sub-groups (below-average, average, and above-average performers). The average score of the question papers in Calculus I was used to form the groups. The post-test results were examined group-by-group to explore whether the method could be used effectively regardless of prior knowledge.

2.3. Sample and Ethics

The effectiveness of the four-stage methodology model for learning cycloidal curves was tested with Hungarian Computer Science Engineering BSc students at the University of Miskolc.

The experimental group comprised 36 students (86.11% male, 13.89% female). The control group comprised 62 students (93.55% male, 6.45% female). The total sample compared 98 students, consisting of 89 men (90.82%) and 9 women (9.18%), as shown in Figure 6. All participants are full-time BSc students and aged between 19 and 22. The experimental group and the control group were of different sizes, but the statistical method chosen to analyze the data was not sensitive to differences in group size.

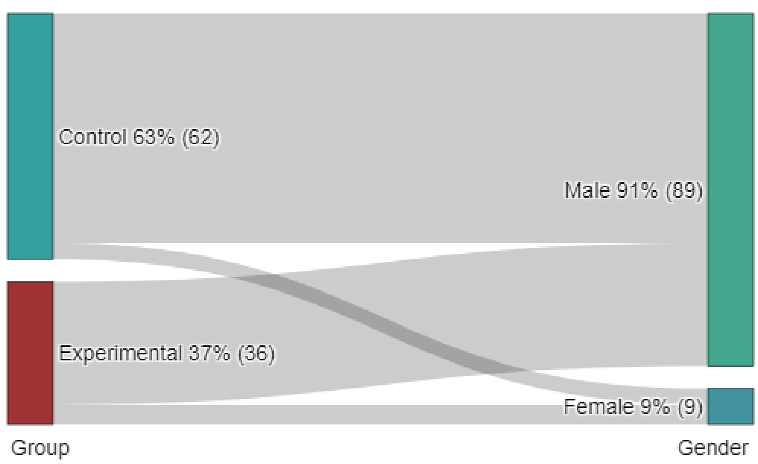

Figure 6. Sankey diagram of the full sample to visualize gender and groups. (The figure was created using DATA*tab* https://datatab.net/ (accessed on 2 October 2024)).

At the beginning of the semester, students were informed that up to 40 students could participate in six extra Robotic-STEAM (R-STEAM) seminars during the semester. Students could register voluntarily. Participants agreed to attend all six seminar sessions and to prepare solutions for the homework assignments. Four of the applicants failed to meet this condition, resulting in an experimental group of 36. The groups in the practical sessions were mixed, i.e., the control and experimental groups were not separated during the frontal teaching. Cycloidal curves are usually covered in the first 4 weeks of the semester. The lectures and practical sessions were held as usual during the experiment in the first four weeks. However, six extra seminars were held so that the experiment took place in the first six weeks of the semester. Only members of the experimental group attended the R-STEAM seminars. Due to the limited number of robots and the training center's limited capacity, the seminars were divided into groups of 20 students.

At the beginning of the semester, students were informed of the research's aims, and all agreed to participate. This study followed the ethical standards set out in the University of Miskolc's Code of Ethics.

2.4. Intervention and Instruments

The Calculus II course lasted 13 weeks and consisted of three 45-min lectures and two 45-min practical problem sessions weekly. Students learned the same material and solved the same exercises during practice sessions. The participants attended the same lectures, while their practice sessions were taught in groups of 20 students on average. There were five practice groups. The teachers of the practice groups consulted each week on the main issues related to the course in order to avoid teacher influence, so the structure of the practice sessions was similar in each group.

The learning processes of the experimental and control groups were synchronized during frontal teaching. Both groups heard the same theoretical material in the lectures, and in the exercises, they took the same types of tasks, working from the same exercise book. The first stage in the four-stage methodological model for learning cycloidal curves is frontal teaching, which was implemented under the same conditions for both the experimental and control groups. The control group did not receive any other intervention.

The experimental group members (36 students) participated in six extra R-STEAM seminars, one weekly for six weeks, where STEAM-based supplementary training was implemented to support the frontal teaching of the theoretical material. A full description of one of the six seminars can be found in Appendix B. The second and third stages of the teaching–learning process were implemented in the seminars according to the 4C principle. The last stage involved extracurricular activities in the form of project work. In these out-class activities, the experimental group students solved homework projects using DGS, as shown in the last column in Table 3.

The post-test, the question paper of Calculus II, was written in the seventh week of the semester. The scores obtained on the question paper were used for the statistical analysis. The task set used for the question paper was the same for the experimental and control groups. Experienced teachers marked the question papers. The question paper exercises were marked using a detailed scoring guide prepared by the lecturer, which included the sub-scores and scoring information. All post-test tasks, along with their corresponding score values, can be found in Appendix C.

2.5. Research Questions

When introducing a new educational model, it is crucial to address several key research questions to ensure its effectiveness, impact, and sustainability. This research aimed to demonstrate the positive effects of the four-stage methodological model for learning cycloidal curves, so the research questions were the following:

- RQ1: Can a positive effect of the four-step model on the learning of cycloidal curves be demonstrated after its introduction in an undergraduate engineering mathematics course?

- RQ2: Which group of students use the new learning model most effectively regarding academic performance?

The results of the participants' question papers were analyzed using statistical methods to address the two research questions regarding the effectiveness and learning outcomes.

3. Data Analysis and Results

In the experiment, the control group was larger (62 participants) than the experimental group (36 participants). The DATA*tab* statistical calculator was used to analyze the data. Table 4 shows the two groups' statistical key figures. The maximum possible score on the question paper was 50. The experimental group has a higher mean score (42.17) compared to the control group (27.15). Similarly, the median score for the experimental group (45) is higher than that of the control group (27). The standard deviations and variances are similar, indicating a comparable level of spread or variability in scores within both groups. However, the experimental group has a slightly higher standard deviation (8.56) compared to the control group (8.18). The range for the control group (7 to 46) is wider compared to the experimental group (24 to 50). The 95% confidence interval for the mean score of the control group (25.07–29.22) does not overlap with that of the experimental group (39.27–45.07), reinforcing the conclusion that the experimental group scores significantly higher. The data show that the experimental group shows significantly higher performance in scores compared to the control group, with higher mean, median, and mode. The confidence intervals for the means do not overlap, suggesting a statistically significant difference between the groups. The variability within each group is similar, but the experimental group has a slightly higher spread around the median.

Table 4. Descriptive statistics for both groups.

	Experimental Group	Control Group
N	36	62
Mean	42.17	27.15
Median	45	27
Mode	50	25
Std. Deviation	8.56	8.18
Variance	73.34	66.88
Minimum	24	7
Maximum	50	46

The violin plot of the sample combined with the box plot includes all the essential data: a marker for the median, a box indicating the interquartile range, and all points of the sample, so it shows the entire distribution of the data (see Figure 7). The violin plot is a powerful visual tool that vividly illustrates the distribution of scores for the control and experimental groups. The distribution in the control group is centered around a score of 27, which aligns with the group's median and mean scores. The distribution in the experimental group is centered around a score of 45, corresponding to the group's median and mean scores. The plot clearly shows that the experimental group achieved higher scores than the control group. Additionally, the width of the violin plot at any given score indicates the density of scores at that level, highlighting the distribution's shape and spread. The kernel density estimation (KDE) method generates the violin plot to smooth the distribution. This method estimates the density of the data, and during the smoothing process, the estimated density may overlap the actual minimum and maximum of the data at some points. Therefore, we can see the "stretches" of the violin plot beyond the actual boundaries of the data.

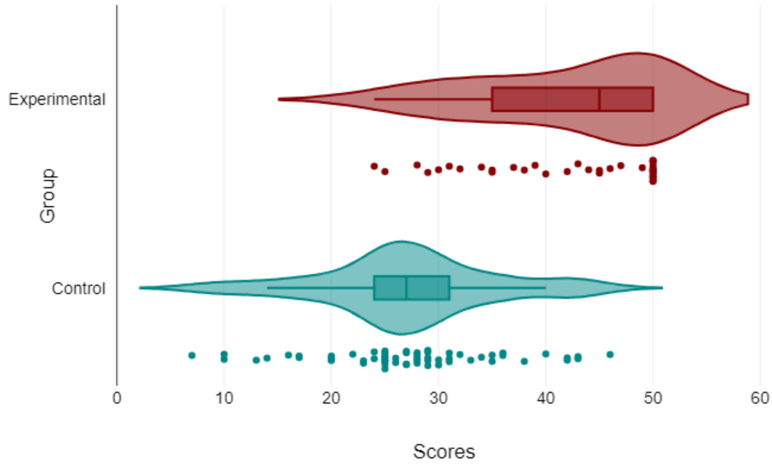

Figure 7. Violin plot combined with box plot. (The figure was created using DATA*tab*).

3.1. Response to Research Question RQ1

The statistical results showed that the experimental group had a higher average score than the control group. However, a statistical hypothesis test is needed to conclude that the experimental group did indeed score better than the control group. The following hypotheses were formulated to answer research question RQ1:

- Null hypothesis: There is no difference between the experimental and control groups concerning the dependent variable.
- Alternative hypothesis: There is a difference regarding the dependent variable between the experimental group and the control group.

Table 5 shows the results of three different statistical tests used to assess whether the data follow a normal distribution.

Table 5. Different statistical tests to check the normality.

	Experimental Group		Control Group	
	Statistics	***p***	**Statistics**	***p***
Kolmogorov–Smirnov	0.21	0.075	0.12	0.287
Shapiro–Wilk	0.84	<0.01	0.97	0.172
Anderson–Darling	2.17	<0.01	0.78	0.042

A high *p*-value (greater than 0.05) suggests that the data do not significantly deviate from normality. In our case, the results of the different tests are contradictory; the results are mixed. The Kolmogorov–Smirnov test shows no significant difference between the two samples, while other tests (Shapiro–Wilk and Anderson–Darling) do. The Shapiro–Wilk and Anderson–Darling tests suggest the data do not follow a normal distribution. To compare the two samples, we used a non-parametric test, the Mann–Whitney U test, which does not assume a normal data distribution. This test helped to determine whether the medians of the two samples were significantly different. Table 6 shows the results of a Mann–Whitney U-test, which is used to analyze whether there is a difference between the two groups.

Table 6. Mann–Whitney U-test values.

	U	*z*	Asymptotic *p*	Exact *p*	*r*
Mann–Whitney U-test	247	−6.42	<0.001	<0.001	0.65

The Mann–Whitney U statistic value (U) is 247. The U value represents the number of times a score from one group precedes a score from the other group in the ranked list of all scores. A smaller U value indicates that the ranks of one group are generally lower than the ranks of the other group, suggesting a difference in the distributions of the two groups. The value of 247 is indeed low compared to the maximum possible value, which means that the scores of the experimental group are generally higher than those of the control group. The maximum value of the U statistic is the product of two sample sizes:

$$\mathrm{U_{max}} = 36 \times 62 = 2232.$$

The z-value (standardized test statistic) is -6.42. This is the standardized deviation from the mean value in a normal distribution, which is used to determine the significance of the U-statistic. The negative z value indicates that the experimental group scores significantly higher. The asymptotic p-value is <0.001. This value represents the probability of observing a test statistic as extreme as, or more extreme than, the observed value under the null hypothesis (which posits no difference between the groups). A p-value of <0.001 is below the common significance threshold of 0.05, suggesting that the result is significant at the 5% level. Another way of calculating the p-value is the exact p-value, which is often used for small sample sizes. It's slightly smaller than the asymptotic p-value and also indicates a significant result at the 5% significance level. The r value is 0.65. This is a measure of effect size and indicates the magnitude of the difference between groups. The r-value, a measure of effect size, is calculated for the Mann–Whitney U test as follows:

$$r = \frac{|z|}{\sqrt{N_{\mathrm{total}}}},$$

where z is the standardized z-value from the test, and N is the total sample size, i.e., the sum of the sizes of the two groups. The interpretation of effect size values was established by the statistician Jacob Cohen in 1988 [83]. A value of 0.65 indicates a high effect size, which shows that the difference is not only statistically significant but also of practical significance.

In summary, the Mann–Whitney U-test showed that the difference between the control group and the experimental group with respect to the dependent variable was statistically significant. The results of the Mann–Whitney U test indicate that the experimental group achieved significantly better results than the control group. The low U-value (247) indicates that the experimental group ranks higher, and this conclusion is reinforced by the very low p-values and the significant effect size. This suggests that the experimental intervention was more effective than the control. Thus, the null hypothesis was rejected, which answers research question RQ1.

3.2. Response to Research Question RQ2

In the experimental group, we tested whether we could find a correlation between the results of the question paper on cycloidal curves and past performance. Given the differences in prior knowledge, we wanted to see what relationship could be identified in the sample. For this study, we used participants' Calculus I average scores. The Calculus II course is in the spring semester; of course, it can only be taken if the Calculus I course was absolved in the previous semester. Similar to Calculus II requirements, Calculus I requires students to write two 50-point question papers during the semester. Three subgroups were formed based on the average of the scores on these two papers. Subgroups of below-average (G1), average (G2), and above-average performers (G3) were created using the usual technique in psychological experiments. The sample mean and standard deviation were used to calculate the lower and upper bounds of the middle interval. Students who performed in the mean $\pm$ 0.5 $\times$ standard deviation range were assigned to group G2. The intervals for the selection are as follows:

$$G1 = [25, 28.445), \quad G2 = [28.445, 33.755], \quad G3 = (33.755, 44].$$

With this selection method $|G1| = 13$, $|G2| = 12$ és $|G3| = 11$, as can be seen in Figure 8.

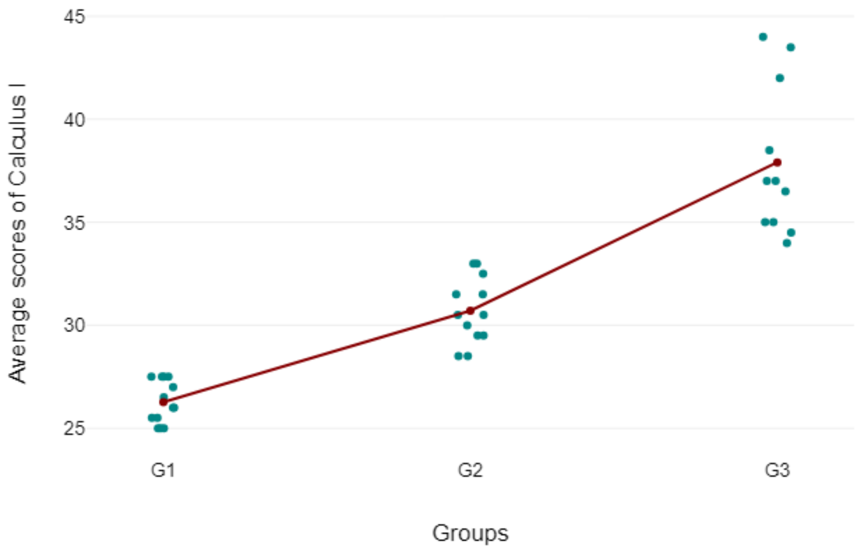

Figure 8. Multi-vari chart of the experimental group according to average scores related to the Calculus I course. (The figure was created using DATA*tab*).

Once the three subgroups were formed, the results of the question papers on cycloidal curves were examined group by group. Table 7 shows the data of descriptive statistics. The mean and median values are similar across the three groups, indicating that the means of the data are not significantly different (see Figure 9). However, the median for G1 is slightly lower (43) compared to the median for G2 (46.5) and G3 (47). The standard deviation and variance are similar in magnitude across all three groups. Still, the variance and standard deviation for the G1 group are slightly higher, suggesting greater variability among the G1 data. The minimum and maximum values are in a similar range.

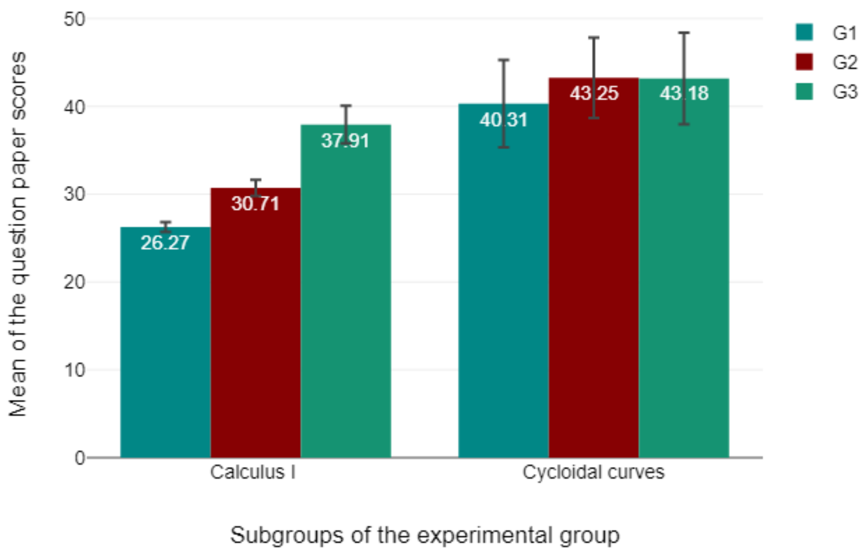

Figure 9. Bar chart of the subgroups of the experimental group showing mean scores and standard deviations. (The figure was created using DATA*tab*).

Table 7. Descriptive statistics for Groups G1, G2, and G3.

	G1	G2	G3
N	13	12	11
Mean	40.31	43.25	43.18
Median	43	46.5	47
Mode	50	50	50
Std. Deviation	9.13	8.09	8.81
Variance	83.4	65.48	77.56
Minimum	24	29	25
Maximum	50	50	50

The following two hypotheses were formulated and tested to answer research question RQ2:

- Null hypothesis: There is no difference between the three categories of the experimental group in terms of the dependent variable (scores of the question paper on cycloidal curves).
- Alternative hypothesis: There is a difference between the three categories of the experimental group in terms of the dependent variable (scores of the question paper on cycloidal curves).

The Kruskal–Wallis non-parametric test was used to determine whether there was a significant difference between the groups because the normality condition was not met in the sample. Table 8 shows the results. χ^2 is the test statistic for the Kruskal–Wallis test. A value of 0.99 suggests there is not much difference between the groups. The larger the χ^2 value, the more evidence there is for differences between the groups. A lower χ^2 value usually suggests that the differences between the groups are not as pronounced. The degrees of freedom in this case are 2. The degrees of freedom for the Kruskal–Wallis test is one less than the number of groups being compared. We have three subgroups, so the degrees of freedom are 2. The resulting p-value was 0.611, meaning that there was no statistically significant difference between the medians of the three groups. This is consistent with the statistical characteristics where means and medians were similar. Typically, a p-value less than 0.05 is considered statistically significant.

Table 8. Kruskal–Wallis test values.

	χ^2	df	p
Kruskal–Wallis test	0.99	2	0.611

Based on the data and the Kruskal–Wallis test results, there is no statistically significant difference among the three subgroups (G1, G2, and G3). The means and medians of the subgroups are very similar, and the variability is also comparable across the subgroups. The p-value of 0.611 indicates that any observed differences are likely due to random chance rather than a true effect. In summary, based on the results of the Kruskal–Wallis test, a p-value of 0.611 indicates that there is no statistically significant difference between the subgroups tested. We retain the null hypothesis, which means that the four-stage model for learning cycloidal curves helped students achieve better academic results regardless of their individual mathematical competencies. Thus, we can answer the RQ2 research question: the four-stage methodology for learning cycloidal curves supports learning achievement regardless of individual differences in prior knowledge; it is not only effective for a certain group of students.

4. Discussion and Conclusions

This research delved into the potential of a novel four-stage methodology for teaching cycloidal curves in university engineering mathematics education, aiming to determine its effectiveness and suitability for diverse student populations. The new learning model implements STEAM-based education in engineering mathematics using ER and DGS.

In the experiment, we conducted a control group study involving 98 first-year computer engineering BSc students. In the first part of this study, we employed a post-test-only design, which means we collected data only after the intervention without administering a pre-test beforehand. By skipping the pre-test, we reduced the risk of biases arising from participants being aware of this study's purpose or goals, which might otherwise affect how they respond or behave during the post-test. As a result, this design helped provide a more precise and more accurate evaluation of the intervention's impact based solely on the post-test results. In the second part of this study, we used a between-groups design. This approach enabled us to compare the effects of the intervention among different subgroups of participants.

Two research questions were formulated and answered by analyzing the scores of the question paper written in a classroom setting. Both the descriptive statistics data and the result of the hypothesis test support the answers to research questions RQ1 and RQ2, so the treatment used is an effective tool for learning cycloidal curves.

In hypothesis testing to answer research question RQ1, we employed a non-parametric test, specifically the Mann–Whitney U test, due to the non-normal distribution of the data. The Mann–Whitney U test demonstrated a statistically significant difference concerning the dependent variable between the control and experimental groups. Expressly, the results indicated that the experimental group achieved significantly better outcomes than the control group. The low U-value (247) suggested higher rankings for the experimental group, which was further supported by very low p-values and a significant effect size. These findings imply that the experimental intervention was more effective than the control. We compared the results with the study conducted by Coufal [84], which utilized the LEGO Mindstorms EV3 kit. Both experiments demonstrated similarly strong results. In the research by Coufal [84], a comparable main research design was employed, featuring a pedagogical experiment that included both experimental and control groups, alongside skill and knowledge assessment through testing. A significant contribution of their study was its verification of the positive impact of educational robotics and project-based learning on developing student competencies, a finding that our experiment corroborates. Additionally, a content analysis technique used in one of the other experiments with the LEGO Mindstorms EV3 robot indicated that project-based learning, when combined with robotics activities within a STEM curriculum framework, significantly benefits students [85]. We also concur with the findings of Goh and Ali [86], who reported positive outcomes in their educational experiment with the LEGO NXT robot. They emphasized the necessity for improved teaching methods to inspire courses, provide more comprehensive support for students facing mathematical challenges, and foster a community atmosphere among STEM learners.

In the experimental group, three subgroups were formed based on students' previous results in Calculus I to answer research question RQ2. The Kruskal–Wallis test yielded a p-value of 0.611, indicating no statistically significant difference between the subgroups. This suggests that the four-stage model for learning cycloidal curves contributed to improved academic outcomes regardless of students' individual mathematical competencies, demonstrating its effectiveness across diverse student groups. In our research, we found that the four-stage methodological model for learning cycloidal curves is an effective approach to the learning process. Our results show that the method can be applied positively to students with below-average, average, and above-average mathematical knowledge.

The experiment indirectly validated Pritchard's claim in [71] that the frontal teaching method can effectively teach mathematics, and thus engineering mathematics, if it is complemented with activities that motivate students. Our research also supports Hassidov's findings in [87] that the teaching method employed in mathematics classrooms is a key and highly influential factor in students' mathematical development. Additionally, it emphasizes the importance of integrating frontal teaching with computer-based mathematical activities. Recent technological innovations have accelerated the integration of digital technologies into mathematics education [88]. The systematic analysis of Cevikbas et al. [88] showed that the most popular technologies in the category of digital resources for mathematical modeling were DGSs. While the four-stage model for learning about cycloidal curves relies heavily on DGS, it also introduces students to an alternative modeling technique by integrating ER, providing them with tangible physical experiences. Additionally, the experiment suggested that, aligning with the findings of Tessema et al. [59], realistic hands-on experiences are essential to the mathematics learning process. This approach ensures that students are actively engaged in learning, fostering a deeper understanding of the subject matter.

The findings of our study on the effectiveness of the novel four-stage model for teaching cycloidal curves are consistent with recent advancements in educational practices that emphasize active learning and technological integration. Current research highlights the importance of hands-on experiences and the use of educational robotics in enhancing student engagement and understanding in mathematics education [41,85,89]. Our results corroborate existing literature that supports the positive impact of innovative teaching methods and PjBL approaches on diverse learner populations, demonstrating improved outcomes across different mathematical competencies [75,76]. Additionally, this study contributes to the growing body of evidence suggesting that integrating digital technologies, like ER and DGS, fosters deeper conceptual understanding and developing problem-solving skills [77,78,80,88] Overall, our findings suggest that adopting modern pedagogical approaches can significantly enhance engineering mathematics education in higher education settings, aligning with contemporary trends in STEM education.

Limitations

Introducing educational robotics into higher education presents several challenges that must be addressed while planning and implementing robotic activities. Adequate laboratories and technical infrastructure are essential for robotics programs. Robotic tools and software often have technical problems and bugs that require time and expertise, hindering the smooth running of classes and reducing the overall learning experience.

The narrowest cross-section is LEGO robot kits. There are good examples of LEGO robots being used in higher education; for example, Avanzato [90] and Udvardy and Beszédes [91] show educational applications of the LEGO Mindstorms EV3 system. However, the LEGO EV3 robotics kit was released in 2013, and since then, many newer technologies and robotic tools have entered the market. Newer kits like the LEGO Education SPIKE Prime feature more advanced sensors, motors, and programming capabilities. Technology evolves rapidly, the EV3's programming environment is nowadays less user-friendly and modern compared to newer systems that are more intuitive and support multiple programming languages, such as Scratch and Python; moreover, the LEGO education SPIKE Prime is more modular and flexible, better suited to the needs of various educational levels and projects. These kits are more accessible to assemble and modify, which is particularly important in education.

The research was conducted at one university and only involved students in computer science engineering. Further research is needed to test the methodology in different universities and with various groups of students. The lack of demographic diversity may be a limitation of our methodological experiment, as the results of experiments in homogeneous groups are difficult to generalize. If the participants are not representative of the different demographic characteristics of the society, the results may be biased and may not reflect the real situation or the different reactions of different groups. The lack of demographic diversity in the experiment meant that important factors such as cultural differences, the impact of social background, or the different experiences of different age groups could not be taken into account when interpreting the results. This study's small sample size (98 participants) is a major limitation. This small sample size may limit the generalizability of the findings to the larger population. A larger sample would provide more robust and reliable results.

Nowadays, the gender distribution in engineering higher education remains unequal. The proportion of females is much lower than males in engineering and computer science [92,93]. The sample in this article was predominantly male (90.82%). This may have affected the study's results. Future research may wish to use a more gender-balanced sample. However, it may also be interesting to repeat the experiment in a course with a higher proportion of females to explore whether the results remain consistent across diverse populations. Unfortunately, we could not conduct such experiments either at the University of Miskolc or at the Šiauliai State Higher Education Institution because the sex ratios of the students did not allow it.

One of the main limitations of the quasi-experimental research design used in the experiment is that it does not allow randomly allocating participants into groups. This means that the experimental and control group members may not be equally representative of the whole population. Because of the lack of random grouping, it is impossible to determine whether the substantial differences observed are due to the experimental intervention or the result of pre-existing differences. Quasi-experimental research design is often used in educational experiments [94], as random assignment is usually not feasible for ethical or practical reasons; it was the case in our experiment too.

The research focused on only one subject: teaching cycloid curves. Further development and research are needed to test the four-step methodological model in other subjects, as the ER activity requires the creation of appropriate robot constructs and projects.

5. Considerations for Future Research

It is crucial to recognize that while the research design and sample size may raise some questions regarding the overall robustness of the research findings, they do not inherently undermine the validity of the results. Nonetheless, these limitations must be carefully considered when interpreting this study's outcomes. To enhance the reliability of future inquiries, it is essential to evaluate the effectiveness of the four-stage methodology for learning cycloidal curves using a larger and more diverse sample size. Specifically, ensuring a more balanced gender representation and incorporating a wider demographic of subjects will provide a more comprehensive understanding of the methodology's impact.

The findings from this experiment suggest that the four-stage approach for learning cycloidal curves holds promise in facilitating the learning process of cycloidal curves. This potential of the four-stage approach for learning cycloidal curves to significantly enhance the learning process is a reason for hope. However, to establish more definitive conclusions, it is imperative to conduct additional studies in this area. Exploring the application of this methodology across various educational institutions and among different student demographics would provide valuable insights and strengthen the generalizability of the results.

In the current study, we relied solely on quantitative measures to assess the outcomes, which limited the understanding of the participants' experiences and attitudes. For future iterations of this experiment, it will be vital to integrate qualitative tools, including soliciting student feedback through questionnaires. By gathering participants' perspectives on the four-stage methodology for learning cycloidal curves, we will not only enrich the data but also better understand the subjective experiences of students, thus providing a more holistic view of the methodology's effectiveness and areas for improvement.

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Data Availability Statement: The data presented in this study are available upon request from the corresponding author due to ethical reasons.

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

Abbreviations

The following abbreviations are used in this manuscript:

STEM	Science, Technology, Engineering, Mathematics
STEAM	Science, Technology, Engineering, Art, Mathematics
ER	Educational Robotics
PBL	problem-based learning
PjBL	project-based learning
DGS	Dynamic Geometry Software

Appendix A. Equations and Graphs of Cycloidal Curves

The curve is a cycloid when the curve is generated by a point on the circumference of a circle that rolls along a straight line. The name of the curve, cycloid, originates from Galileo Galilei, who studied the curve in detail [95]. If the fixed curve is a circle and the generating point lies on the circumference of the rolling circle, then the cycloidal curve is called an epicycloid or a hypocycloid, depending on whether the rolling circle is situated outside or inside the fixed circle [96]. All main types of cycloidal curve families are summarized in Table 1. We note that epi- and hypotrochoid curves were first described by Albrecht Dürer in his work *"Instruction in measurement with compasses and straight edge"* in 1525. Dürer called these curves spider lines because the lines he used to construct the curves looked like a spider [45]. Cycloidal curves were named by Ole Rømer in 1674 while studying the best form for gear teeth. The claim that Ole Rømer was the first to propose using cycloidal curves for gear tooth profiles can be found in the works of Gottfried Wilhelm von Leibniz and Christian Huygens. Unfortunately, this cannot be directly proven because Rømer's published work was destroyed in the great fire of 1728 in Copenhagen [97].

The parametric equations of a plane curve are usually given by two different functions depending on the same variable, in the form $(x(t), y(t))$ for some real parameter t, where x and y are continuous functions of t. If a circle of radius r rolls around the outside of a fixed circle of radius R, and the generating point (pole) P is attached to the moving circle a distance d from its center, the parametric equations of the epitrochoid traced by P are as follows:

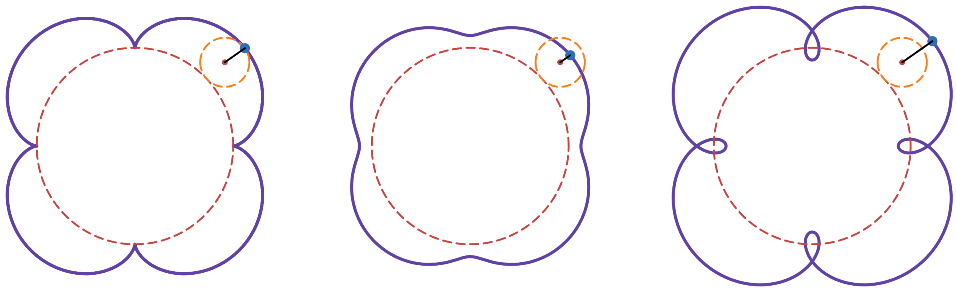
$$\begin{aligned} x(t) &= (R+r)\cos t - d\cos\left(\frac{R+r}{r}t\right), \\ y(t) &= (R+r)\sin t - d\sin\left(\frac{R+r}{r}t\right), \end{aligned} \tag{A1}$$

where the independent variable $t \in \mathbb{R}$ denotes the angle between a line through the center of both circles and the x-axis [98]. In the sequel, the quantities R, r and d in (A1) will be referred to as parametric constants and d will be called the pole distance. Considering the geometric interpretation of cycloidal curves, we assume that the parametric constants R and r are positive real numbers and d is a non-negative real number. Three cases can be distinguished based on the relationship between d and r. If $d = r$, then the curve is an epicycloid (Figure A1a), if $d < r$, then it is a curtate epitrochoid (Figure A1b), and if $d > r$, then the curve is a prolate epitrochoid (Figure A1c). An epicycloid always touches the fixed circle $(d = r)$; a curtate epitrochoid does not touch the fixed circle $(d < r)$, while a prolate epitrochoid crosses it $(d > r)$.

If a circle of radius r rolls around the inside of a fixed circle of radius R, and the pole P is attached to the moving circle a distance d from its center, the parametric equations of the hypotrochoid traced by P are as follows:

$$\begin{aligned} x(t) &= (R-r)\cos t + d\cos\left(\frac{R-r}{r}t\right), \\ y(t) &= (R-r)\sin t - d\sin\left(\frac{R-r}{r}t\right), \end{aligned} \tag{A2}$$

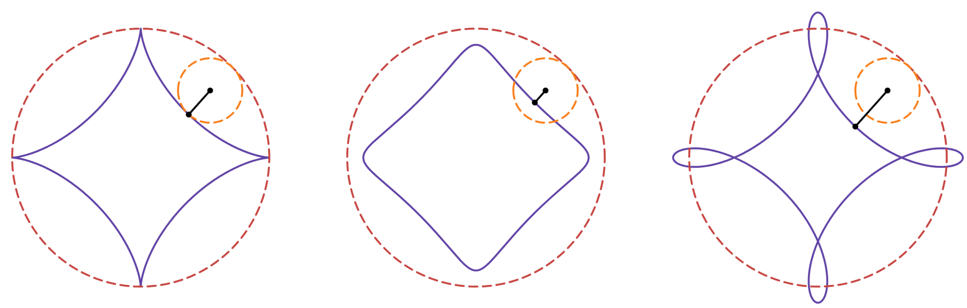
where $t \in \mathbb{R}$ [98]. Three cases can be distinguished based on the relative values of d and r. If the distance from the fixed point on the moving circle to the center is equal to the radius of the moving circle $(d = r)$, then the curve is a hypocycloid. If the point is within the radius of the inner circle $(d < r)$, the curve is a curtate hypotrochoid. With $d > r$, it is a prolate hypotrochoid. A hypocycloid touches the fixed circle $(d = r)$; a curtate hypotrochoid does never touch the fixed circle $(d < r)$, and a prolate hypotrochoid crosses it $(d > r)$.



(**a**) (**b**) (**c**)

Figure A1. Epitrochoids $(R = 4r)$. (**a**) Epicycloid. (**b**) Curtate epitrochoid. (**c**) Prolate epitrochoid. (Figures were created using Desmos https://www.desmos.com/geometry (accessed on 2 October 2024)).

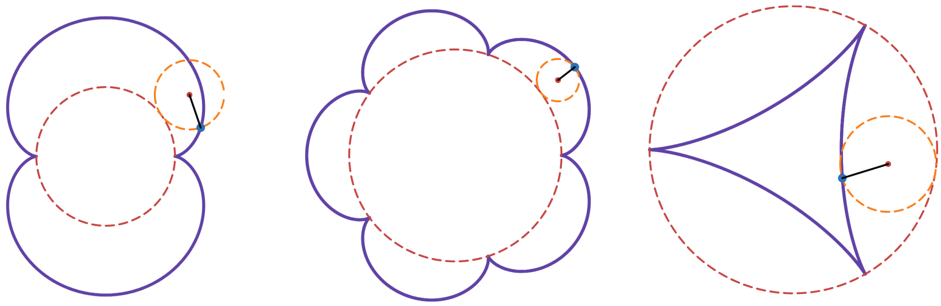
In addition to this grouping, further important curves can be obtained by a particular choice of parametric constants. For example, if $d = 0$, it can be easily seen from Equations (A1) and (A2) that the curves are circles with radius $R + r$ and $R - r$ $(r < R)$. A hypotrochoid with $R = 2r$, $r \neq d$ is an ellipse. The cardioid is an epicycloid with parametric constants $d = r = R$, and the hypocycloid with $d = r = \frac{R}{4}$ is an astroid (Figure A2a).



(**a**) (**b**) (**c**)

Figure A2. Hypotrochoids $(R = 4r)$. (**a**) Hypocycloid. (**b**) Curtate hypotrochoid. (**c**) Prolate hypotrochoid. (Figures were created using Desmos).

For hypocycloids and epicycloids, consider the fraction $r/R = p/q$, where p and q are relatively prime natural numbers. Then, the denominator q of the reduced fraction has an important meaning since q gives the number of cusps, where a cusp is defined as a point in which the curve meets the fixed circle. For example, the cardioid is a 1-cusped epicycloid, the nephroid is a 2-cusped epicycloid (Figure A3a), and an epicycloid with five cusps is called a 'ranunculoid' (Figure A3b). A 2-cusped hypocycloid (Tusi couple) is a line segment, a 3-cusped hypocycloid is a deltoid (Figure A3c), and the astroid is a 4-cusped hypocycloid (Figure A2a). A trochoid can have infinitely many cusps if the r/R ratio is not rational; in this case, the generating circle will never return to its initial position, and the curve will keep having new cusps as the circle keeps rolling around the base circle [43,54,98].



(**a**) (**b**) (**c**)

Figure A3. Multi-cusped epi- and hypocycloids. (**a**) Nephroid. (**b**) Ranunculoid. (**c**) Deltoid. (Figures were created using Desmos).

Appendix B. Teaching Cardioid Using the Four-Stage Model for Learning Cycloidal Curves

One of the most interesting shapes in the varied world of two-dimensional curves is the cardioid, which belongs to the family of epicycloids. Its practical applications have kept it in the spotlight today. The methodology developed to teach the cardioid curve is presented below, starting from the second stage, using the elements of the 4C principle.

Appendix B.1. Connect

In the seminar that follows the theoretical presentation, it is worthwhile to make the connection from at least three different angles. First, a brief overview of the history of the cardioid is provided, along with a discussion on its practical applications. Next, the cardioid is presented as a caustic curve, followed by an exploration and demonstration of its double-generation property. The animations produced by the Desmos graphing calculator effectively support the visual representation of the two methods of generating the cardioid curve.

Appendix B.1.1. History and Practical Applications of Cardioids

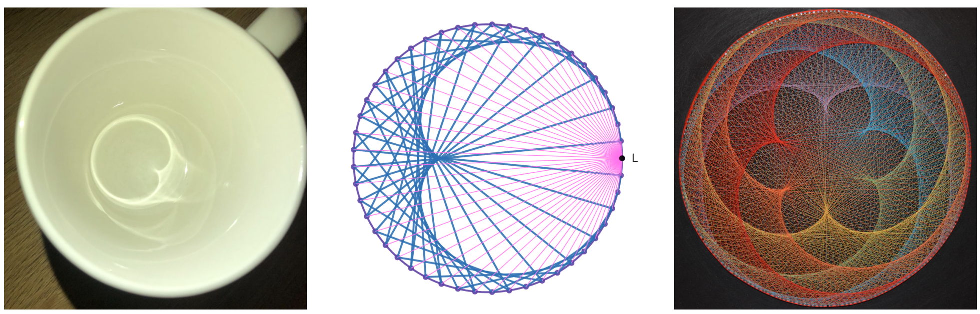
There is no certainty about who discovered the cardioid. There is written evidence that in 1637, the amateur mathematician Étienne Pascal—father of Blaise Pascal—investigated the more general case of the cardioid, the limaçon, but not the cardioid specifically. In 1674, the Danish astronomer Ole Rømer considered the cardioid when he was searching for the optimal gear tooth shape, and several sources credit him with the discovery [96,99]. The cardioid as an epicycloid was investigated in 1691 by Jacob Ozaniaill, and afterward, it appeared in the works of several prominent mathematicians. Bernoulli, L' Hospital, Maclaurin, Cramer, and many others also worked with the cardioid [100]. In 1708, Philippe de la Hire was the first to calculate the arc length of the cardioid [99]. Its name comes from the Greek word for heart. Interestingly, it was not until 1741 when Johann Castillon gave the curve its name in a paper in the Royal Society's Philosophical Transactions.

The cardioid curve has intrigued mathematicians for centuries because of its properties, its graph's beauty, and practical applications [98,99]. The cardioid appears in many seemingly diverse areas of mathematics, playing an essential role in fractal geometry; for example, the central figure of the famous Mandelbrot set is a cardioid curve [99]. Cardioid shapes appear on rolls and bobbins to ensure the uniform layering of yarn in the textile industry and the signal strength pattern of a type of radio antenna [101]. The cardioid antenna takes its name from the shape of the radiating beam. Typically, a single-band antenna is most commonly used in terrestrial communications. The use of cardioid-shaped fractals in antennas allows coverage of all commercial frequency bands in the 1.8–30 GHz frequency range while maintaining the small size of the antenna due to the space-filling capability of the fractals; therefore, fractal antennas can be used in energy harvesting systems as well as IoT, WLAN, mobile MIMO and satellite communication systems and radars [102]. In parallel, the cardioid also plays a significant role in audio engineering because a cardioid directional pattern in a microphone provides a relatively wide pick-up zone [103]. When audio engineers need a unidirectional microphone—one highly sensitive to sounds generated directly in front of the microphone and less sensitive to those generated next to or behind it—they use a microphone with cardioid directionality [104]. Cardioid finds various applications in complex analysis, plant physiology, and engineering [103]. From a didactical point of view, the wide and illustrative practical use of cardioid antennas and microphones offers an excellent opportunity to motivate engineering students and raise their awareness of the interesting properties of cardioid.

Appendix B.1.2. A Popular Experiment: Cardioid in a Cup

In studies on the cardioid, the cupping experiment to demonstrate its caustic property is frequently mentioned. This experiment is popular because it requires minimal equipment and is easy to perform [103,105].

It can be performed using not just an empty cup, but also with a liquid, for example, coffee or tea, upon which the heart-shaped curve can be displayed. Using the flashlight function on mobile phones, it is easy to form the cardioid by illuminating it from the rim of the cup, and the photo can be taken with another phone so that, in a few minutes, one can have a good-quality photo of the cardioid curve (Figure A4a). With this experiment, we prove that the caustic curve for the circle is a cardioid if the light rays are emitted from a fixed point on the circle and reflected from the circle according to the laws of physics (Figure A4b).



(**a**) (**b**) (**c**)

Figure A4. Cardioid, as a caustic curve of the circle. (**a**) At the bottom of the cup. (**b**) Reflected rays. (**c**) Flower string art. The Flower string art with six cardioids made by Kaydeekat [106].

The cardioid is then obtained as an envelope of lines, but only the caustic curve is visible in the cup, not the lines (the light rays). In string art, the principle of producing a caustic curve is often used, where the straight lines are modeled with a thread [107,108], so that not only the envelope curve is visible, but also the straight lines (segments), as can be seen in Figure A4c. Because of its simplicity, the cup experiment is a good choice to stimulate interest, but the exploration and solution of the related phenomenon should be placed at the end of the seminar, which will establish the framework and, thus, provide a sense of completeness for the participants.

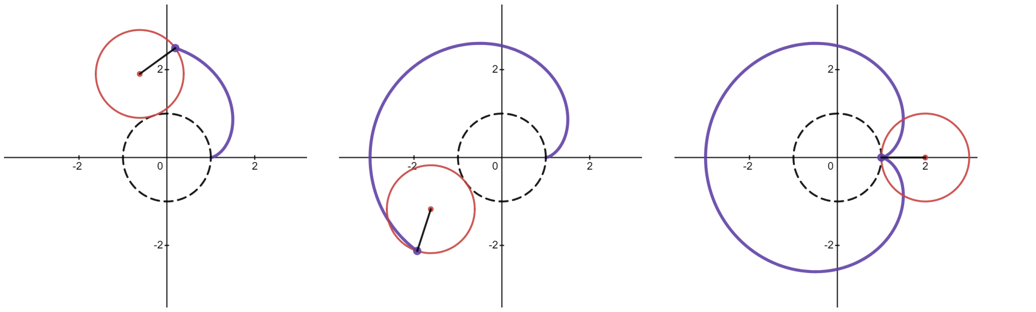
Appendix B.1.3. Double Generation Theorem

The cardioid can be derived in a surprisingly wide variety of ways. It is most often defined as an epicycloid: a cardioid is a plane curve followed by a fixed point on the circumference of a circle of radius r as the circle rolls without sliding along a fixed circle of radius r [43]. The parametric equations for the cardioid curve are as follows:

$$\begin{aligned} x(t) &= r(2\cos t - \cos 2t) \\ y(t) &= r(2\sin t - \sin 2t), \end{aligned} \tag{A3}$$

where $t \in [0, 2\pi]$. The derivation of (A3) can be found in [96].

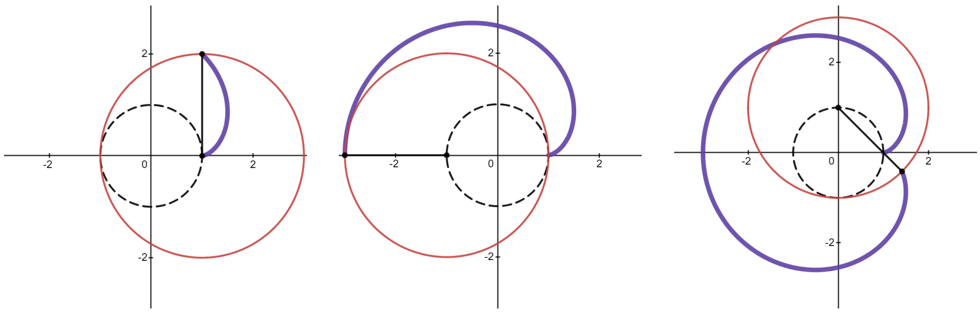
Figure A5 shows three steps from the production by animation for the cardioid in Equation (A3) when $r = 1$. The period is equal to the circumference of the moving circle, so it is 2π in this case.



(**a**) (**b**) (**c**)

Figure A5. Generating the cardioid as an epicycloid for $r = 1$. (**a**) $t = \frac{3\pi}{5}$. (**b**) $t = \frac{6\pi}{5}$. (**c**) $t = 2\pi$. Animation of the generation: https://www.desmos.com/calculator/dlz1jubuzy (accessed on 6 July 2024). (Figures and the animation were created using Desmos).

Usually, the cardioid is discussed primarily from the perspective of an epicycloid in lectures, with other possibilities often overlooked. However, due to its dual generating property, the cardioid can also be described as a hypocycloid(see Figure A6). The cardioid is the path traced by a point on the circumference of a circle with radius $R = 2r$, where the circle rolls "inside" a fixed circle of radius r without sliding [96]. The dual generation is easily illustrated by making spectacular animations using Desmos.

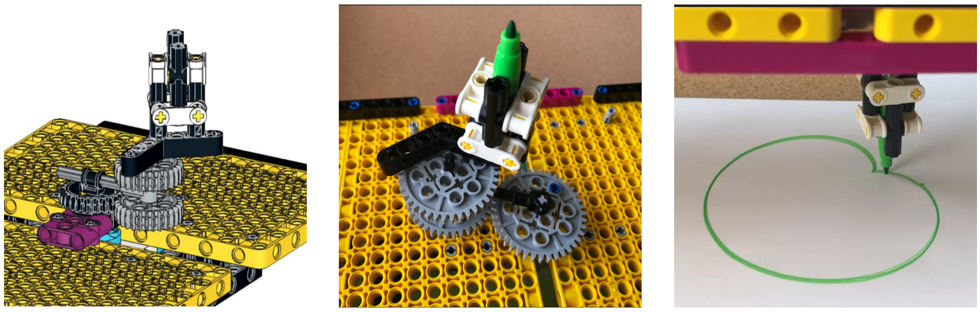


(**a**) (**b**) (**c**)

Figure A6. Generating the cardioid as a hypocycloid for $r = 1$ and $R = 2r = 2$. (**a**) $t = \pi$. (**b**) $t = 2\pi$. (**c**) $t = \dfrac{7\pi}{2}$. Animation of the generation: https://www.desmos.com/calculator/vgts1kwl1k (accessed on 6 July 2024). (Figures and the animation were created using Desmos).

Appendix B.2. Construct

Based on the cup experiment, the question naturally arises: How can we plot the cardioid curve with high accuracy? Another way to gain direct experience is to take advantage of STEAM-based education by using educational robotics to draw the cardioid curve. The Spikograph 2.0 robot (see Figure 4) is operated using a simple program: a single turn of the motor produces the cardioid curve. We created a detailed construction manual for the robot using Studio 2.0 software. The robot can be quickly built in a short time. Small groups of up to 3–4 students are recommended for building and testing. To build the basic robot, we used double gears (46,372) with a diameter of 28 mm and teeth on both sides to represent the moving circles, and a LEGO Turntable (LEGO Turntable, 4,652,236) of the same size to model the fixed circle (Figure A7a). The rolling gears are powered by a motor, and a continuously adjustable shaft has been employed to facilitate easy gear changes during reconstruction. The felt-tip pen is mounted at a circumferential point on the moving gear. The rolling gears were doubled to solve the precise positioning and stable mounting of the drawing head. With this construction version, the pen holder head can be fixed at several points using a LEGO Technic lever. Cardioids of different sizes can be drawn by rebuilding the robot after replacing the gears. In Figure A7b, LEGO Technic gears with 40 teeth (364,902) were used for the construction. In this case, the positioning of the axis for rotation is different from when using the turntable. The application of the 40th gear is advantageous because the length of the strings passing through the cusp from the perimeter points of the drawn curve is 8 cm, so the area and length of the arc can be easily calculated using integral calculus. Building and drawing takes about 20 min, including rebuilding, if properly prepared. In [63], we discussed the process of drawing cardioid curves using LEGO robots, alongside the theoretical background. In addition, we presented guided projects that utilize these cardioid-drawing robots.



(**a**) (**b**) (**c**)

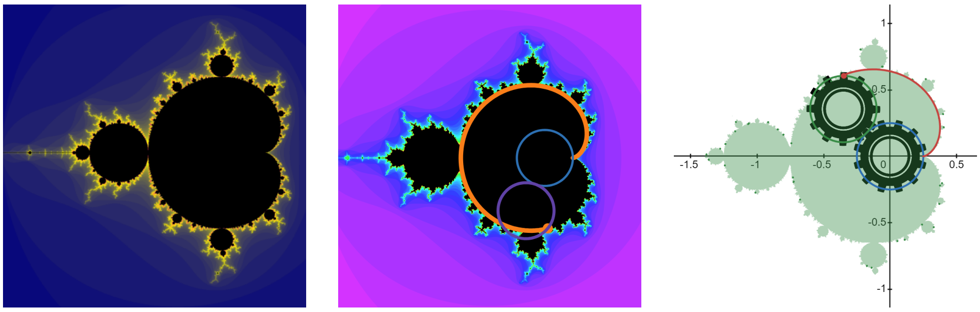
Figure A7. Cardioid drawing Spikograph 2.0 robot. (**a**) Drawing head. (**b**) After rebuilding. (**c**) Robot-drawn cardioid. (The first subfigure was made with Studio 2.0 software, the second two are self-made photos).

Appendix B.3. Contemplate

The word fractal was coined in 1975 by mathematician Benoit Mandelbrot to describe a set of shapes whose infinitely complex, self-similar forms reveal repetitive patterns. The dazzling computer-generated images of fractals have captured the attention and motivated the interest of students in mathematics more so than any other mathematical discovery in the last century [99]. The Mandelbrot set is defined as the set of complex numbers $c \in \mathbb{C}$ such that the sequence $\{z_n\}$ defined by the recursion $z_n = z_{n-1}^2 + c$ with initial value $z_0 = 0$ remains bounded for all $n \geq 0$ [109]. The Mandelbrot set features a fundamental cardioid shape adorned with numerous bulbs directly attached to it [110]. The main cardioid is the big heart-shaped region of the Mandelbrot fractal.

The project task in the contemplate phase was connected to the main cardioid in the Mandelbrot fractal. The aim was to animate the generation of the cardioid in the fractal, where the rolling of the circles over each other results in the points of the cardioid curve. Two solutions were proposed to visualize the Mandelbrot set. In the first, the Mandelbrot set can be loaded into Desmos as an image; in this case, the image can be positioned arbitrarily. In the second one, the fractal is generated in Desmos, and the path to the iteration is provided to the students. The project aimed to generate a central cardioid shape using circles. Considering that the groups working on the project started with their own ideas, the initial cardioids had different sizes and orientations, resulting in different solutions.

The earlier stage of the methodology provided significant support for the task because, essentially, the robot's operation had to be modeled with animation; all the knowledge was provided, and the students were also shown the animation of cardioid production as both epi- and hypocycloids when the double generation theorem was presented. The effectiveness of the work with robots was demonstrated by the fact that among the solutions, there were animations where the gears appeared, as seen in Figure A8.



(**a**) (**b**) (**c**)

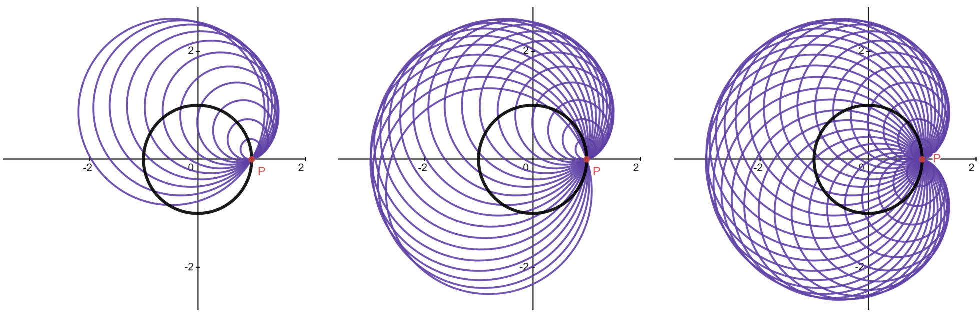
Figure A8. Mandelbrot fractal and student solutions for the project. (**a**) Mandelbrot fractal. (**b**) A student solution. (**c**) Another student solution with gears. (The first subfigure was generated using the free Mandelbrot Set Explorer generator, the last two subfigures were created using Desmos).

Appendix B.4. Continue

The last stage of the methodology was implemented by setting interesting project tasks that could be solved with the Desmos dynamic geometry software https://www.desmos.com/geometry (accessed on 2 October 2024), focusing mainly on cardioid visualization. The cardioid can be constructed as an envelope of curves in several different ways. When generating a cardioid, various animation options are available, with the most common approach being to display members of the curve family sequentially. A common feature of all animations is the use of lists. In creating attractive solutions, students are also introduced to properties of the cardioid that extend beyond the basic knowledge required by the curriculum.

Appendix B.4.1. Cardioid as the Envelope of a Pencil of Circles

Consider a given circle (the generator circle) and a distinguished point P on the generator circle. The set of all circles that pass through P and have their centers on the generator circle form a pencil of circles. The envelope of this pencil is a cardioid [43]. The diameter of the resulting cardioid is twice the diameter of the fixed circle, and its cusp is at point P. The cardioid was generated in 34-step iterations using the Desmos graphing calculator to create Figure A9.



(**a**) (**b**) (**c**)

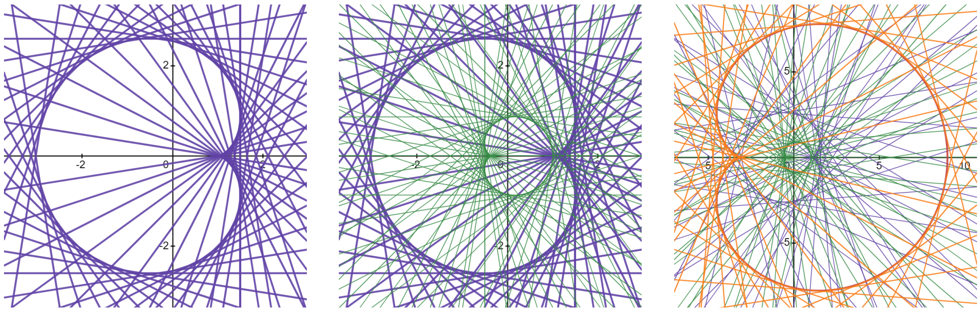
Figure A9. Cardioid as the envelope of a pencil of circles. (**a**) Step 11. (**b**) Step 20. (**c**) Last step. Animation of the generation: https://www.desmos.com/calculator/nvkxenx7ek (accessed on 6 July 2024). (Figures and the animation were created using Desmos).

Appendix B.4.2. Evolute and Involute

Several simple student projects can be formulated to investigate the tangent lines. A spectacular figure can be drawn by plotting the cardioid tangents (Figure A10a). The evolute of a curve is defined as the locus of the center of curvature or the envelope of the normals of a curve. Like all cycloidal curves, the evolute of the cardioid is a mirror-image cardioid, though not of the same size (Figure A10b). The parametric equations of the evolute are as follows:

$$\begin{aligned} x(t) &= \frac{1}{3}r(2\cos t + \cos 2t) \\ y(t) &= \frac{1}{3}r(2\sin t + \sin 2t), \end{aligned} \tag{A4}$$

where $t \in [0, 2\pi]$, when we have the cardioid defined by (A3).



(**a**) (**b**) (**c**)

Figure A10. Cardioids drawn with tangent and normal lines. (**a**) Tangent lines. (**b**) Evolute. (**c**) Evolute and involute. Animation of the generation of the evolute: https://www.desmos.com/calculator/vsdi02x51i (accessed on 6 July 2024). (Figures and the animation were created using Desmos).

If the plane curves g_1 and g_2 are given, and the curve g_2 is the evolute of g_1, then g_1 is the involute of g_2. We can make the previous problem more complex by sketching the involute of the given cardioid (A3). The involute of the cardioid is a mirror-image cardioid in a bigger size. The parametric equations of the involute:

$$\begin{aligned} x(t) &= 3r(2\cos t + \cos 2t) \\ y(t) &= 3r(2\sin t + \sin 2t), \end{aligned} \tag{A5}$$

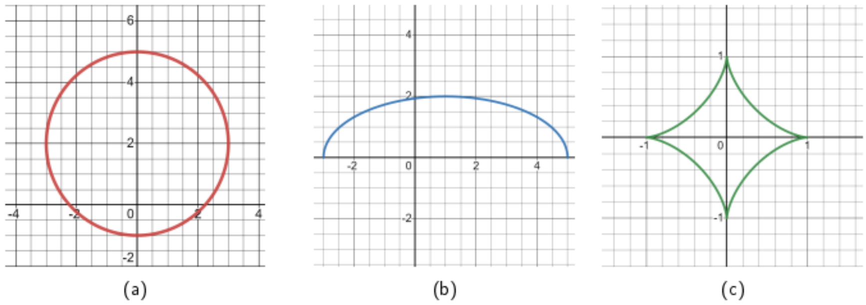
$t \in [0, 2\pi]$. The number of iterations is 61 for the first two subfigures and 51 for the third in Figure A10. To solve these exercises, one needs to understand the parametric equations of the cardioid in vector form, the derivative of a parametrically defined curve, and the equations for the tangent and normal lines of a curve.

Appendix C. The Post-Test

1. How is a cardioid curve generated? (5 points)
2. How many points of intersection do the following two parametric curves have? (3 points)

$$\begin{cases} x(t) = 3\cos t \\ y(t) = 3\sin t \end{cases}, \quad 0 \le t \le \pi \qquad\qquad \begin{cases} x(t) = 4\cos t \\ y(t) = 2\sin t \end{cases}, \quad 0 \le t \le 2\pi$$

3. Identify the curves shown in the following figures and write down the parametric equations for all three curves. (9 points)



4. Find $\frac{dy}{dx}$ and determine an equation of the tangent line to the given curve at $t_0 = \frac{\pi}{4}$. Sketch the curve and the tangent line in the Cartesian coordinate system. (9 points)

$$\begin{cases} x(t) = \cos^3 t \\ y(t) = \sin^3 t, \quad t \in [0, 2\pi] \end{cases}$$

5. Calculate the area and circumference of the sector bounded by the curve $r(\varphi) = 6 \sin \varphi$, $\varphi \in [0, \pi]$ using integral calculus. Make a sketch! Give the Cartesian coordinate equation of the curve. (10 points)
6. Sketch the curve below and determine its arc length. (5 points)

$$\begin{cases} x(t) = t - \sin t \\ y(t) = 1 - \cos t, \quad t \in [0, 2\pi] \end{cases}$$

7. Find the area inside the cardioid $r(\theta) = 1 + \cos\theta$ and outside the circle $r = 1$. (9 points)

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Article

Norwegian Public Health Nursing Students' Experiences with the Transition from Classroom to Online Lectures: Benefits and Challenges

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Abstract: The integration of technology in higher education increased online courses available to students, although traditional face-to-face interaction remains dominant. The COVID-19 pandemic forced a rapid transition to emergency remote teaching (ERT), impacting public health nursing (PHN) education in Norway, which primarily consists of adult learners. The impact of the transition to online-only lectures on these students remains largely unexplored. The aim of this study is to examine how Norwegian PHN students experienced the transition from traditional classroom lectures to online-only lectures during the global pandemic. It also identifies the self-reported advantages and challenges associated with online-only lectures and whether this transition affected their perceived learning outcome. A cross-sectional sample of public health nursing (PHN) students (n = 275) participated in a survey in from May to November 2020. The questionnaire was specifically developed for this study and covers student motivation, perceived benefits and challenges of transitioning to online lectures, peer collaboration, and self-assessed learning outcomes. It was distributed to the PHN students via their respective education's LMS system. Most PHN students managed the technical aspects of the abrupt transition to online-only lectures effectively. They reported high digital competence, found the transition relatively easy, and remained motivated to continue their studies. Despite these positives, students reported a reduction in learning outcomes compared to classroom lectures. Challenges included the missing face-to-face interaction with peers, difficulties in managing childcare, and issues with structuring their studies.

Keywords: public health nursing (PHN) students; online learning; online-only lectures; classroom lectures; adult learners

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1. Introduction

The integration of technology into higher education transformed both learning and teaching. Advances such as the internet and computer technology contributed to a global paradigm shift, leading universities and colleges to embrace online learning. This shift resulted in a substantial increase in the number of online courses available to students [1,2]. Since the 1980–1990s, online learning as a mode of delivery has been employed both exclusively and as a complement to traditional classroom teaching [2,3]. Despite this development and increased access to online solutions, the tradition of in-person interaction between students and lecturers remained a strong standing in higher education. Face-to-face lectures and in-person interaction in other pedagogical activities remained one of the most commonly used approaches in higher education [4].

This changed when the COVID-19 pandemic emerged in the spring of 2020. To control the spread of the virus, governments worldwide implemented social distancing measures and temporarily shut down societies, which led universities and colleges to suspend all in-person activities including face-to-face lectures [5–8]. The urgent need to continue educational activities while maintaining social distancing measures required a swift transition, and most universities and colleges quickly shifted all their activity to emergency remote teaching (ERT) [9,10]. In contrast to online learning as planned activities, ERT constitutes a temporary shift of instructional delivery to an alternate delivery mode due to crisis circumstances [10]. With the rapid transition to ERT, staff had to create and prepare teaching material for both real-time (synchronous) and on-demand learning (asynchronous) for students almost overnight [8,10]. When Norway experienced a national shutdown of society caused by the COVID-19 pandemic, universities and colleges rapidly transitioned to ERT, forcing students to rely entirely on online solutions to continue their education [7]. However, this abrupt shift to fully digital learning occurred against a backdrop where, prior to the pandemic, the Norwegian government already decided to focus on digitalisation in education [11,12]. Despite this, the actual implementation of digital tools was limited in scope. Various learning management systems (LMS) were primarily used for administrative tasks, such as submission of exams, mandatory assignments, and distributing syllabi, rather than for interactive learning. Communication between students and teachers typically occurred through email or other online platforms, but face-to-face lectures and in-person interaction still dominated the educational experience [12]. When the shift to ERT became necessary, many students and educators faced significant challenges in adapting to the new, fully online environment, revealing a critical tension between pre-existing digitalization efforts and the reality of its integration into teaching and learning practices, including public health nursing (PHN) education. PHN education is a specialised post-graduate programme designed to prepare nurses to become specialists in public health promotion and illness prevention work for children and adolescents 0–20 years, as well as their guardians and caregivers [13]. In Norway, the majority of PHN students are adult learners or adult students ($\geq$25 years), who often balance multiple responsibilities, such as managing families and children [14]. These adult learners in higher education face several challenges compared with their younger counterparts, as they frequently have to manage multiple roles and complex identities, including those of spouses, parents, students, and colleagues [15,16]. Even though PHN students were accustomed to some online tools, lectures and other pedagogical activities were mainly conducted in face-to-face settings. With the abrupt shift to ERT, where all activities moved online, little is known about how adult learners experienced this transition, and the potential advantages and disadvantages they encountered.

This study aims to explore how Norwegian PHN students experienced the transition from traditional classroom lectures to online-only lectures during a global pandemic.

Additionally, this study aims to assess whether the transition to online-only lectures impacted the student's perceived learning outcome; and finally, to describe the student's self-reported advantages and challenges associated with online-only lectures.

Thus, we hypothesised that the PHN nurses considered their learning outcome as poorer after online learning only was introduced compared to the pre-pandemic situation. Further, we hypothesised that the level of perceived learning outcome was associated with age of the respondents, e.g., we anticipated younger PHN students to be more positive to the e-learning only experience.

1.1. Background and Previous Research

1.1.1. Online Learning

The evolution of the World Wide Web (WWW) and its associated technologies in the 1990s marked a significant turning point in education, creating new opportunities for the development of web-based courses and lectures [17]. As the accessibilities to required facilities and learning platforms became more available, the interest and opportunity for developing web-based courses and lectures online coalesced [18], all of which paved the way for the development of LMS [19].

While this technological shift was transformative, it also led to an ongoing struggle in defining what online learning truly encompasses. Terms such as "online learning", "e-learning", "distance learning", and "digital learning" emerged in academic literature after 1995 [19–22], but the lack of consistency in their use points to deeper conceptual ambiguities.

Although online learning or e-learning can be broadly defined as the use of technology to access educational experiences [16,17], or as a range of electronic applications and tools to support education and training [23], these definitions are often incomplete and the focus on technology in many definitions tends to overshadow the core aspect of learning itself. Singh and Thurman's systematic review highlighted this issue, identifying 46 different definitions of online learning, each interspersed with overlapping terms and concepts. While technology, interactivity, and temporal aspects—such as synchronous (real-time) or asynchronous (delayed) learning—are frequently cited as essential components, many definitions fail to adequately incorporate the pedagogical elements of the learning experience itself.

Singh and Thurman make an argument for a more comprehensive definition that includes elements of interactivity and learning, urging a shift from viewing learning as merely a technological substitute for the classroom to recognising it as a dynamic, evolving pedagogical space. Other themes found in most definitions, but not in all, were, among others, physical distance and comparison to the traditional classroom [19].

Three modes are described that differentiate online education: adjunct mode, mixed mode, and fully online mode, which offer a framework for understanding varying levels of integration between technology and academic activities. In the adjunct mode, the Internet supplements traditional education by allowing students and faculty to access research resources and communicate with peers. While this mode is present across all academic levels, its role is often supportive rather than central.

Mixed mode, on the other hand, integrates technology into teaching, but it often remains inconsistent in its application. While it enhances learning through online discussions or group projects, these activities frequently function as isolated components rather than as integral parts of the overall course design, but still a more seamless blending of traditional and digital learning. Finally, the fully online mode relies exclusively on the Internet for both content delivery and interaction, with all academic activities conducted online. This mode represents a complete departure from the physical classroom, offering a wholly digital learning environment. While it enables place- and time-independent learning, it also risks isolating students and creating a more transactional learning environment. The absence of face-to-face interaction can diminish the sense of community, which is crucial for student engagement and motivation. Moreover, the effectiveness of this mode relies heavily on the quality of course design, instructor presence, and digital literacy among both educators and students. In summary, while these modes and attributes highlight the flexibility and potential of online education, they also reveal gaps in implementation. The success of any online educational model depends on thoughtful, intentional course design and a recognition of the distinct pedagogical needs of digital environments. Without this, the technology's full capacity to enrich and transform learning remains underutilised [2,21,24–26].

1.1.2. Emergency Remote Teaching (ERT)

When COVID-19 emerged, universities and colleges suspended all face-to-face lectures and other in-person learning experiences, forcing a rapid shift to ERT to maintain study progression. As described by Hodges et al. (2020), ERT differs from online teaching as it is a response to a crisis, characterised by a temporary shift in instructional delivery to an alternative mode. This approach differs from online learning, which is planned from the beginning with intentional instructional design. In contrast, ERT employs fully remote teaching solutions, such as lectures online (online-only lectures), as a temporary measure for courses typically delivered in a face-to-face format, with the expectation that instruction will return to its original format once the crisis or emergency is resolved [10]. The use of ERT became a solution in the early days of the COVID-19 pandemic, but also for other emergencies such as armed conflicts or in cases with natural disasters. Unlike planned online education, ERT leaves little time for preparation or establish infrastructures, and the existing resources and systems must be put to use. Further on, both students and lectures are removed from their regular learning environments, making them fully dependent on technological solutions [27,28].

In the early phase of the closedown caused by the pandemic, it was expected that the closedown would be short-lived, and societies could return to normal. However, as the pandemic persisted, the ERT, which was hastily put in place, began to take on a more permanent character as universities and colleges kept on delivering education in a fully remote environment [29].

1.1.3. Benefits and Challenges with Online Learning

Several studies examined the advantages and disadvantages of online learning within the educational sector, considering both students' and teachers' perspectives [30–36]. Among the well-known advantages are the cost-efficiency with online learning, as online learning can reduce institutional and student expenses [30]. Flexibility is another benefit, allowing both students and teachers to engage with learning at any time and place [37]. However, these advantages depend on the teaching being carefully designed and well-organised to ensure students can effectively engage with the material asynchronously. To achieve this, course material must go beyond merely presenting lecture slides and should include a variety of comprehensive educational materials that facilitate independent learning [38]. A well-designed and pedagogically sound prepared online learning environment should also allow for self-paced study, enabling students to progress through the material at a speed that suits their individual learning needs, whether slower or faster [31,32]. Additionally, the elimination of geographical barriers removes the necessity for travel, making education more accessible [39].

For effective online learning to succeed, even when students are at home, access to technological devices such as personal computers, smartphones, and broadband is essential, especially for students studying from home [40]. Successful online teaching also depends on the student's attitude, more precisely, positive or negative attitude to digital mediums. Students' skills and familiarity with specific technologies and web applications are significant predictors of their attitude towards online learning. Those with more experience and confidence in using digital tools are generally more receptive to online learning. In contrast, students who lack such skills may find the transition to online learning challenging. Furthermore, factors such as prior computer training, years of computer use, ownership of devices, and the frequency of use all contribute to students' comfort and effectiveness in an online learning environment [41–43]. This suggests that while access to technology is fundamental, it is equally important to provide support systems that help students develop the necessary digital competencies [44,45]. Online learning, while offering significant benefits, is not without its challenges. One of the most notable drawbacks is the absence of face-to-face interaction, which can diminish the sense of community among students and between students and teachers, [32,33,36]. The lack of personal connection may lead to feelings of isolation, which can negatively impact motivation and engagement. Moreover, the lack of a structured framework in online learning requires a high level of self-discipline among students. Students must manage both their time and learning activities independently, which can be difficult for those who are not accustomed to self-directed learning. These challenges underline the need for robust instructional design and support systems to guide students in the process and maintaining their academic focus [32].

Other challenges include inadequate institutional support, unstable network structure, and a lack of information and communications technology (ICT) knowledge among students and teachers [32,34,46]. Benefits and challenges of EMT do not differ significantly from those of online teaching. Ferri et al. (2020) found that the transition to ERT became a pragmatic solution when the COVID-19 pandemic hit. Furthermore, several challenges were also identified, including technological, pedagogical, and social issues. Technological challenges involved students' lack of access to computers or smartphones and the strain on broadband network when a large number of users were online simultaneously. Pedagogical challenges included the lack of digital skills among students and limited time for teachers to design and develop quality online courses. Finally, social challenges included the lack of interaction between students and teachers as well as the students themselves [47]. These obstacles emphasise that while online education and ERT offer pragmatic solutions, they require careful planning and substantial support to overcome technological, pedagogical, and social barriers. Without addressing these issues, the potential of online learning will remain underutilised, leaving many learners at a disadvantage [44].

1.1.4. Adult Learners

In the evolving society with demographic shifts, new forms of labor division, technological advancements, ongoing reskilling and upskilling, and increased digitization are becoming increasingly prevalent. These factors are shaping future skill requirements and creating a demand for new knowledge and competencies within the population, highlighting the necessity of lifelong learning [48–51]. Additionally, the incorporation of technology into educational practice democratised access to learning, providing a wide range of opportunities for diverse groups, including adult learners, to pursue further education, enhance professional competencies, and engage in personal enrichment activities [18,52]. This resulted in a rapid increase in the number of adult students over the past decades [16]. By 2022, approximately 47% of working-age adults (ages 25–64) in the European Union were participating in education and training programs [53]. In Norway, the guarantee of free education for adult learners reflects the commitment to lifelong learning as an important principle in the education policy [54]. However, policy alone does not mitigate the substantial barriers many adult learners encounter. Unlike younger students, adult learners in higher education often face several unique challenges that can impact their learning experiences and academic success. They often have to balance their studies with other significant responsibilities, such as family obligations, work alongside studying, technical issues with software or internet access, a lack of suitable study environments at home, limited interaction with fellow students and teachers, and other personal commitments. These competing demands can lead to stress and may affect their academic performance and engagement [46,55–57]. As technology and online platforms become more central to education, some adult learners face difficulties adapting to these new tools, which can hinder their learning process [46,58,59]. While it is not uncommon for students to work while studying, adult students are required to contribute to their household's financial stability by working alongside their studies [46]. A report from Statistics Norway on students' living conditions in 2021 found that 81.4% of Norwegian students between 30 and 44 years old had paid work alongside their studies [60]. This dual responsibility can place significant demands on their time and energy, as they must juggle academic commitments with the need to earn an income [46].

Adult learners often have different learning needs and styles compared to traditional students [61]. Knowles' framework of andragogy outlines six key principles of adult learning, which explain these differences [62]. The first principle is the learner's need to understand the relevance and purpose of their learning, including what they will learn, how it will be taught, and why it is important. The second principle is self-directed learning, which emphasises the learner's ability to take control over their learning processes and objectives. The third principle recognises the importance of prior experience, acknowledging that adult learners bring diverse backgrounds, accumulated knowledge, and personal biases into the learning environments. These experiences shape how they engage with new material and contribute to their self-identity as learner.

The fourth principle, the readiness to learn, suggests that adults are most motivated to learn when their current life circumstances require a need for new knowledge or skills. The fifth principle is orientation to learning, which posits that adults prefer problem-centered learning that is relevant to real-life situations. They are more engaged when the learning directly applies to solving practical problems they encounter in their personal or professional lives. Finally, the sixth principle is motivation to learn, which asserts that adults are highly motivated when the learning outcome is directly applicable to solving significant life problems [63,64]. In sum, while Knowles' principles of andragogy provide a useful framework, they should be applied with caution. Adult learners are diverse, and their motivations, experiences, and learning environments vary significantly. A more flexible and nuanced understanding of adult learning is required to address the complexities they face in today's dynamic educational landscape [65].

Motivation among students is a critical factor influencing their academic success and overall engagement in the learning process. It encompasses two main types, intrinsic motivation where students are driven by a personal interest for the subject and extrinsic motivation, which is based on external rewards or pressure such as grades, career prospects, or societal expectations [66,67]. For many adult learners in higher education, motivation is often closely tied to practical outcome, particularly career advancement. When they perceive a clear connection between their studies and professional aspirations, their motivation to perform well tends to increase [61].

Sogunro (2015) identified eight motivating factors important for adult learners' motivation factors, the quality of curriculum, its relevance to adult learners need, interactive classroom environment, effective management practices, progressive assessment, timely feedback, self-directedness, conducive learning environment, and academic advising practices [68].

2. Materials and Methods

2.1. Design and Sampling

This study uses a cross-sectional design and aims to recruit a sample representative for the target population, more precisely Norwegian PHN students.

The research team contacted teachers in the respective PHN study programmes by e-mail, providing detailed information about the study along with a link to the questionnaire. Additionally, we followed up with a telephone call to offer further details about the study and provide assistance if needed. Due to confidentiality constraints, the respective PHN education institution could not provide us with contact information for their students. Consequently, information about the study and the link to the questionnaire was disseminated to PHN students through the learning management systems (LMS) utilised by the respective universities/colleges. This allowed students to maintain anonymity while accessing and responding to the questionnaire. Information regarding the study was incorporated into the introduction section of the questionnaire, and students were required to provide active consent before proceeding to the questionnaire items. Students who did not provide consent were automatically excluded from participation.

We employed an anonymous self-administered web survey utilising Net survey (Nettskjema) [69], a Norwegian tool designed for creating and administration online surveys tailored for research purposes. The platform is user-friendly, allowing students to access questionaries and provide responses conveniently using a computer, tablet, or cell phone. Three reminders were disseminated and posted on the LMS system of the respective universities/colleges.

Participants were recruited from eight PHN study programmes, ensuring representation from all regions of Norway. The included universities or colleges vary in size and geographical location, covering both urban and rural areas. Additionally, the PHN students have diverse socio-cultural backgrounds [14].

Data collection occurred during the COVID-19 pandemic, specifically between mid-May 2020 and November 2020, which was 2–8 months into the Norwegian lockdown. Given that PHN study programmes offer both full-time and part-time options, the students' progression in their studies at the time of data collection varied. However, due to the lockdown restrictions, all the participants were exposed to online-only lectures only during the time frame of this study. We did not have access to contact information, making it impossible for all PHN students to participate in this study. As a result, we were unable to obtain data on students enrolled in participating institutions who did not consent to participate (non-responders). Consequently, we lack complete and accurate information about the entire PHS student population, as we only have data from those who responded. This limitation prevented us from comparing responders and non-responders, making it impossible to assess possible selection bias.

2.2. The Questionnaire

To the best of our knowledge, no suitable national or international questionnaire was developed and/or validated by spring 2020 that fully addresses our study aims.

Consequently, we developed a new questionnaire in Norwegian, tailored to meet our specific research objective. Additionally, this study was conducted during the first phase of the COVID-19 lockdown, aiming to capture the students' experiences under emergency circumstances in the overnight transitions from classroom lectures to online-only lectures.

The items in the questionnaire were developed based on a comprehensive review of the literature on online education, with relevant questions incorporated into the instrument. Prior to its distribution to the PHN study programs, the questionaries underwent a review by university colleagues. Their feedback was integrated, and the questionnaire was subsequently revised accordingly.

The questionnaire includes demographic variables such as age, sex, civil status, number of children, and the age of the children. Additionally, it features questions addressing the student's motivation, their self-perceived benefits and challenges associated with the abrupt transition from classroom lectures to online-only lectures, collaboration with fellow students, and the students' self-assessed learning outcomes from the previous week when subjected to online-only lectures.

The questions were designed to be answered using yes/no responses, a fixed set of predefined alternatives, or on a Likert ordinal scale ranging from 1 to 6 (1 as not motivated at all to 6 as very motivated; 1 as very dissatisfied to 6 as very satisfied; 1 as very bad to 6 as very good; and 1 as totally agree to 6 as totally disagree). For the question in which students were asked to self-report their perceived learning outcome over the past week, a follow-up question was included, prompting the students to elaborate on their responses.

To facilitate the analysis, several responses were dichotomised and presented as numbers and percentages. The questions utilising a Likert scale were dichotomised into the following categories: motivated (category 4–6) versus not motivated (category 1–3), satisfied (category 4–6) versus not satisfied (category 1–3), and agree (category 4–6) versus not agree (category 1–3). Additionally: the civil status variable was merged into the categories of married/cohabiting, divorced, and single.

2.3. Ethical Considerations

All participants provided written informed consent upon recruitment and did not receive any financial compensation. The questionnaire did not include questions about personal health information or other sensitive data; therefore, the Norwegian Regional Committee for Medical and Health Research Ethics concluded that additional ethical approval was not required (2020/143629/REK-Sør-Øst). Consent from the Norwegian Centre for Research Data (SIKT) was not required because no identified information of the participant, electronic or otherwise, was collected. There are no conflicts of interest involved in this project, and it did not receive any external funding.

2.4. Statistical Analyses

Categorical variables were presented as frequencies and percentages. Crude associations between pairs of categorical variables were assessed with Pearson's chi-square test. p-values < 0.05 were considered statistically significant, and all tests were two-sided.

Data were handled in the Statistical Package for Social Sciences (SPSS), version 27 (SPSS Inc., Chicago, IL, USA).

3. Results

A total of 275 PHN students returned the questionnaire; almost all responders were females (97.8%). The majority of PHN students were between 30 and 40 years old (53.8%), married or cohabiting (85.8%), and had children (77.8%). Among those with children, the majority had children under the age of 11 years old (75.8%) (Table 1).

Table 1. Study sample.

Variables. n = 275	n (%)
Age	
<30 years	57 (20.7)
30–40 years	148 (53.8)
>40 years	70 (25.5)
Gender	
Female	269 (97.8)
Male	6 (2.2)
Civil status	
Married/cohabiting	236 (85.8)
Divorsed/singel	39 (14.2)
Children	
Yes	214 (77.8)
No	61 (22.2)
Variable. n = 214	n (%)
Age children	
<6 years	113 (52.8)
6–11 years	55 (25.7)
>11 years	46 (21.5)

3.1. The PHN Students Experience with the Transition to Online Lectures

At the time this study was conducted, the vast majority of students (89.1%) attended online-only lectures, with 83.7% expressing satisfaction with this format (Table 2). Overall, 53.8% of students reported finding the transition from traditional classroom lectures to online-only lectures relatively easy (score 4–5), while only 16.7% found this transition difficult (score 1–2).

Furthermore, a substantial majority (82.9%) of the participants perceived their digital competence to be good (scale 4–6).

Fewer than one-fifth of responders received assistance in managing online lectures, with support primarily provided by family and friends. Among students who collaborated with fellow students, approximately two-thirds (57.5%) did so within the context of mandatory assignments (Supplementary Table S1). Additionally, more than one-half of the responders, approximately six in ten, reported missing being able to collaborate with fellow students in a face-to-face setting (Supplementary Table S1).

There were no statistically significant associations between the students' reported digital competence, their motivation to continue their studies, their satisfaction with online-only lectures or their learning outcome, and age and how the students experienced the transition to online-only lectures was (Supplementary Tables S2–S5).

The vast majority of students (92%) reported being motivated to continue their studies. However, our data still reveal a statistically significant age-related pattern: the older the participants were, the higher the proportion of students who reported being motivated to continue their studies. Among those who were not motivated to continue, only 14.3% were 40 years and older, whereas nearly 43% belonged to the youngest age group (<30 years) (Table 3).

Table 2. PHN student's experience with online-only lectures.

Item:	n (%)
Have you attended online-only lectures?	
Yes	245 (89.1)
No	30 (10.9)
Total	275 (100)
If yes, how satisfied are you with online-only lectures?	
Satisfied (4–6)	205 (83.7)
Not satisfied (1–3)	40 (16.3)
Total	245 (100)
How was the transition from face-to face lectures to online-only lectures?	
Easy (4–5)	148 (53.8)
Neutral (3)	81 (29.5)
Hard (1–2)	46 (16.7)
Total	275 (100)
How do you assess your digital competence?	
Good (4–6)	228 (82.9)
Not good (1–3)	47 (17.1)
Total	275 (100)
Did you received help managing the online-only lectures?	
Yes	51 (18.5)
No	224 (81.5)
Total	245 (100)
I received help from: (n = 51 (100%))	
Family and friends	35 (68.6)
Staff at University/college	16 (31.4)
Total	51 (100)
How motivated are you to continue your education?	
Motivated (4–6)	254 (92.4)
Not motivated (1–3)	21 (7.6)
Total	275 (100)

Table 3. Association between age and motivation to continue their studies.

Age Group	Motivated [1] n (%)	Not Motivated [2] n (%)	Total n (%)	*p*-Value
<30 y	48 (18.9)	9 (42.9)	57 (20.7)	0.049 [3]
30–40 y	139 (54.7)	9 (42.9)	148 (53.8)	
>40 y	67 (26.4)	3 (14.3)	70 (25.5)	
	254 (100)	21 (100)	275 (100)	

[1] Scale 4–6, [2] scale 1–3, [3] Fisher's test by Monte Carlo.

3.2. Comparing Learning Outcomes in Online-Only Lectures with Classroom Lectures

When the students self-reported their perception of the previous week's learning outcome from online-only lectures compared to classroom lectures, nearly half (44%) felt they learned less, while only one in ten responders (9.5%) thought the learning outcome was better in online-only lectures (Table 4).

Table 4. PHN students' self-reported learning outcomes in online-only lectures compared with classroom lectures. n = 275.

Online-Only Lectures Are:	n (%)
Better than face-to-face lectures	26 (9.5)
The same as the face-to-face lectures	78 (28.4)
Less than face-to-face lectures	121 (44.0)
I do not know, wait, and see	50 (18.2)
Total	275 (100)

The students were asked to rate (on a scale from 1, totally disagree, to 6, totally agree) whether they believed online-only lectures were as instructive as classroom lectures, and a statistically significant association was found between age and agreement with this statement ($p = 0.034$). A smaller proportion of younger students perceived online-only lectures to be as instructive as classroom lectures compared to the oldest (>40 years) students. Among those over 40 years of age, only one in four (n = 18) did not agree, whereas this proportion was 40.4% and 43.9% among those under 30 and between 30 and 40 years of age, respectively (Table 5).

Table 5. The relationship between age category and students' thoughts of whether online-only lectures were as instructive as classroom lecture.

Age Group	Not Agree [1] n (%)	Agree [2] n (%)	Total n (%)	*p*-Value
<30 y	23 (40.4)	34 (59.6)	57 (100)	0.034
30–40 y	65 (43.9)	83 (56.1)	148 (100)	
>40 y	18 (25.7)	52 (74.3)	70 (100)	
Total	106 (38.5)	169 (65.1)	275 (100)	

[1] scale 4–6, [2] scale 1–3.

Students were given the opportunity to elaborate on their responses. Those who reported a lower learning outcome (89 out of 121) and those who reported a better learning outcome (25 out of 26) provided additional comments. PHN students who reported lower learning outcomes from online-only lectures compared to classroom lectures primarily reported missing interaction with fellow students and teachers as the main reason. They also reported difficulty concentrating and a perceived lack of structure. On the other hand, students who reported better learning outcomes from online-only lectures indicated that this format was more practical and flexible. They also found it easier to concentrate and felt more motivated in online-only lectures (Table 6).

Table 6. The PHN students' elaboration on their answer to learning outcome in online-only lectures.

Student's Elaborations:	
Students who reported less learning outcomes	n (%)
They missed interaction, discussions, and the opportunity to ask questions of their fellow students and teachers.	49 (55.0)
They had difficulty concentrating and felt online-only lectures lacked structure.	16 (18.0)
There were no lectures, cancelled lectures, poor-quality lectures, and technical problems.	15 (16.9)
Caring for children.	4 (4.5)
Other (such as could not choose one alternative, did not understand the question).	5 (5.6)
Total	89 (100)
Students who reported better learning outcomes	n (%)
They found online-only lectures to be flexible, easier to concentrate on, and more motivating.	17 (68.0)
Online-only lectures saved time travelling.	4 (16.0)
Other (better lectures, did not understand the question).	4 (16.0)
Total	25 (100)

3.3. Challenges in the Transition to Online Lectures

When asked about challenges experienced during the transition to online-only lectures, 75.6% of students reported difficulties. The most frequent answers included caring for children (29.8%); a lack of contact and feedback from fellow students and teaching staff (13.6%); and difficulties structuring their studies (12.0%). Only one in four (24.4%) students reported they encountered no challenges (Table 7).

Table 7. Challenges PHN students experienced during the transition from classroom lectures to online-only lectures.

Items	n (%)
Caring for children	82 (29.8)
No challenges	67 (24.4)
Difficulty structuring my studies	33 (12.0)
Lack of contact with and feedback from my fellow students	21 (7.6)
Bad internet connection	18 (6.5)
Limited physical space in my house	16 (5.8)
Other challenges besides those listed	13 (4.7)
Lack of contact with and feedback from professors and administration	11 (4.0)
Uncertainty what the best pedagogical solution is	7 (2.5)
Lack of IT equipment	5 (1.8)
Been sick with COVID-19	2 (0.7)
Total	275 (100)

4. Discussion

This study aimed to examine the experience of Norwegian PHN students during the sudden shift from traditional face-to-face classroom lectures to online-only lectures. The study focused on identifying the self-reported advantages and challenges the students encountered, as well as their perceived learning outcomes. The main findings indicate that, while the majority of students found the transition to be relatively easy and were satisfied with the online lectures, they also reported reduced learning outcomes and several challenges related to online-only lectures.

As anticipated, younger students were more satisfied with e-learning-only outcomes compared to older students.

4.1. Transition to Online-Only Lectures

The majority of students rated their digital competence as good and found the transition from classroom lectures to online-only lectures to be easy. Less than 20% of the students received help in managing their online-only lectures, and those who did primarily relied on support from families and friends (Table 2).

The high digital competence reported by PHN students can partly be attributed to the generally high digital literacy within the Norwegian population [70,71].

In Norway, digital skills are essential for participation in the labor market, education, and various aspects of daily life, including social interaction [72]. A 2021 report on digital competence in Norway, based on interviews with 3004 respondents age 16 years and older, found that both students and working professionals in Norway demonstrate a high level of digital competence [73]. Admission to PHN programs at Norwegian universities or colleges requires a bachelor's degree in nursing [13] typically accompanied by at least one year of work experience. Therefore, it is reasonable to assume that most PHN students were already were familiar with digital tools and computers prior to commencing their PHN education, given their prior academic and professional background. Moreover, access to technological devices, such as personal computers and smartphones is widespread in Norway, with broadband available to 98% of the Norwegian population [72,74], a context that applies to PHN students as well. Most PHN students also expressed satisfaction with the online-only lectures. These factors likely contribute to the smooth transition to online learnings, at least from a technical perspective. Our findings align with those of Peytcheva-Forsyth (2018), who found that students with a positive attitude toward online learning were generally experienced computer users in their daily lives, professional, and educational activities [41].

We anticipate an association between students' age and their perception of the the transition to online-only lectures, however our data did not reveal any such association. This might be explained with the fact that a great majority of the participants reported high levels of digital competence. To the best of our knowledge, no prior studies reported similar findings. However, factors such as feelings of loneliness, isolation, and a lack of interaction with fellow students may have influenced their responses. Several studies highlighted that loneliness and social isolation were prevalent across the population, including students during the COVID-19 pandemic [75–78].

4.2. Learning Outcome in Online-Only Lectures and Students' Motivation

Although the majority of PHN students was motivated to continue their studies and rated their digital competence as high, they reported a decreasing learning outcome in online-only lectures compared to classroom lectures (Table 4). Notably, the oldest students (>40 years) found online-only lectures to be less instructive than face-to-face lectures compared to the younger age groups (<30 and 30–40 years). Additionally, 44% of PHN students perceived their learning outcomes from online-only lectures as inferior, while only 9.5% believed that online lectures offered better learning outcomes than traditional classroom-based lectures (Table 5).

These findings are in line with research, which also found that students were generally satisfied with online teaching despite reporting reduced learning outcomes. For example, a study from Indonesia among 238 students aged 17–40 years during the COVID-19 pandemic found that 91.5% of the students felt they did not gain as much knowledge through online learning as compared to traditional in-person mode [79]. Likewise, a Norwegian study among nutrition education students reported comparable results [7].

However, it is important to note that studies comparing learning outcomes between online-only lectures and face-to-face lectures show inconsistent results. A scoping review from 2021 on this topic revealed that out of 91 studies, 37 (41%) reported better learning outcomes with online learning, 17 (18%) concluded that face-to-face teaching led to a better learning outcomes, while 37 (41%) reported no significant difference between face-to-face and online learning [80].

Factors that contribute to students' learning outcomes are complex with several internal and external factors at play [81]. One of the most important elements for achieving successful learning outcomes is the student's motivation to study [82,83].

We found that most PHN students expressed satisfaction with the online-only lectures, and further reported they were motivated (category 4–6) to continue their studies even if the circumstances changed. Interestingly, we found that a larger proportion of older ($\geq$30 years) students reported higher levels of motivation compared to their younger (<30 years) fellow students (Table 3).

Adult students are described to have a higher motivation towards their studies than traditional students [62,84]. According to Knowles' theory of andragogy, key principles include adults' readiness and motivation to learn, assuming that adults are self-directed learners, purposeful, and driven by internal rather than external factors [62]. Research indicates that adult students' level of motivation and achievement in learning are also influenced by factors such as age and prior work experience, using this as a valuable resource in their learning [15,85]. Kimmel (2016) found that students aged 25–34 were primarily motivated by the desire for a new career, while those over 35 had a range of motivations, including career advancement, salary increases, and the desire for greater respect from peers [86].

This suggests that adult learners often have strong intrinsic motivation for self-improvement, particularly in expanding their knowledge and developing critical thinking skills. Although we lack specific data on whether these factors apply to PHN students, the findings align with the broader characteristics of adult learners. Additionally, the social relations students have with peers and faculty members play a significant role in their academic success [87–89]. Among the students who reported reduced learning outcomes (Table 4) and elaborated their answers, the majority cited missing in-person interaction, collaboration, and face-to-face discussions with fellow students and teaching staff as key reasons (Table 6). Although most students engaged in online collaboration, primarily for mandatory tasks, the majority expressed that they missed the opportunity for face-to-face collaboration (Supplementary Table S1). Students construct knowledge within a social context through interaction and feedback from others [88,90].

Moreover, those students who interact with peers and faculty members generally report higher motivation and satisfaction compare to students with less social interaction [87,91].

A study by Paechter and Maier found that university students preferred face-to-face interaction with fellow students when establishing personal relationships, particularly in situations requiring collaboration on tasks or the development of conceptual knowledge. Additionally, students favoured face-to-face communication with teaching staff when deepening their understanding and establishing relationships with the teaching staff [92]. Previous studies suggest that when designing online courses and lectures, it is crucial to facilitate meaningful interaction between students and teaching staff. Recommendations include implementing live chats, online discussion forums, regular webinars with teaching staff, virtual office hours, and other interactive measures to enhance student engagement [93,94].

Other reasons for reduced learning outcome mentioned by the PHN students include difficulty concentrating and a lack of structure. These issues, along with other disadvantages associated with online lectures, such as the feeling of isolation, loss of motivation and self-discipline, boredom, and difficulties with self-organising capabilities, are documented in previous studies [6,32,95].

The students also reported cancellations of lectures, poor-quality lectures, and teachers' technical problems as reasons for their reduced learning outcomes in online lectures (Table 6). Considering that the facilitation and knowledge of teaching staff are important determinants of students' learning outcomes [96], inadequate instructional design of online courses can influence the students' satisfaction and learning outcomes [97]. According to Castro, the learning experience is shaped primarily by students, educators, and course content [94]. Therefore, educators need to pay special attention to the planning and design of online courses or lectures, focusing on key elements such as flexibility, personalization, the use of small group learning, and intentionally designed interactions [94,98,99]. A small proportion of students reported better learning outcomes in online-only lectures, stating that they found it easier to concentrate, felt more motivated, and saved time travelling (Table 6). These benefits with online learning are described in previous studies [82]. Students have different learning styles and some students prefer to study at their own pace or from home, and they find that online learning offers better self-regulating learning than plenary learning [92].

A study by Biwer et al. [96] examined how university students adapted to the shift from face-to-face to online education and adapted four profiles: the adapters, the maintainers, the surrendered, and the overwhelmed. The adapters were those who reported being more motivated and better able to regulate their attention, time, and effort in the new situation. They appreciated the ability to study at their own pace and to pause online-only lectures to control and monitor their understanding. However, even these students reported missing social contact and interaction with their peers and teaching staff.

4.3. Challenges

Despite that most students found the transition to online-only lectures to be relatively easy, 75.5% of PHN students reported several challenges. Many of these students were adults with families, and one of the challenges was caring for children (Table 7). This study was conducted during the COVID-19 lockdown, a time when children who typically attended daycare centres and older children ($\geq$6 years, 47.2%) who usually attended schools were forced to stay at home. As a result, PHN students had to manage their own studies while also caring for younger children or arranging home-schooling for the older ones. A study by Manze et al. (2021) found that female college students with children during the COVID-19 lockdown often shifted their focus from their studies to support their children's learning [100]. The increased burden for families, particularly on women with children during the epidemic, are documented in other studies as well [101,102].

In general, adult learners often have to manage other roles and more complex identities than younger students, such as that of a spouse, parent, student, and colleague [15]. Markle (2015) found that female adult learners (>25 y) with children experienced a significant increase in responsibilities and obligations associated with the student role [103]. Additional challenges reported by the PHN students include limited space in their homes and a bad internet connection. Our findings are in line with previous studies which also found the same challenges among students attending online teaching, including online-only lectures [5,7,32].

This study offers valuable insights into the experiences of adult learners, more precisely, PHN students during the abrupt shift from face-to-face lectures to online-only lectures. The research highlights the benefits and challenges of online learning, which are crucial for informing the development of targeted learning activities and have significant implications for educational practice. Findings could guide the planning and design of online education to meet the needs of adult learners who face different challenges compared to younger students. The study emphasises the need for educational institutions, where learning environments are typically designed for younger, more traditional students, to adapt and provide supportive measures tailored to the needs of adult learners.

4.4. Limitations

Our sample is sizable, including respondents from rural and urban areas. At the time this study was conducted, the students were all at the same stage in their study programme. However, there are several limitations to this study. First, the study had a response rate of 63%, which many introduce bias. Additionally, the study was conducted during the COVID-19 lockdown in Norway, and stress related to the unprecedented situation could have influenced the low response rate. Furthermore, we have no information about the students who did not participate, making it impossible to determine whether there is any difference between participants and non-participants. Another limitation is the questionnaire. To the best of our knowledge, no existing questionnaire addressed the specific aim of our study, necessitating the development of a custom instrument. Given that this study was conducted shortly after the lockdown, pre-testing of the questionnaire was not feasible. The response rate on surveys is often low, and as a measure to maximise the response rates, the questionnaire was intentionally kept short.

Regarding the question about students' perceived learning outcome from the previous week, we have no information on the students' actual achieved learning outcomes since we had no opportunities to monitor and assess the quality of their work. Additionally, it is important to consider that the sudden change brought about by the COVID-19 pandemic may have influenced the students' experiences and perceptions. This includes uncertainties related to the pandemic, societal shutdowns, and concerns about the future, which could have affected the learning outcomes reported by PHN students and others.

5. Conclusions

The study examined Norwegian PHN students' experience with the abrupt shift from face-to-face lectures to online-only lectures during the COVID-19 pandemic. Although most students found the transition easy and were satisfied with online-only lectures, they reported reduced learning outcomes and several challenges. High digital competence, largely due to Norway's digital literacy, facilitated the transition. Despite challenges such as the lack of interaction with peers and teachers, balancing family responsibilities, and technical issues, the majority of students remained motivated to continue their studies. The use of online learning is here to stay, and the shift to online-only lectures during the COVID-19 pandemic provided valuable insights into the potential and challenges of digital learning. Overall, the study highlights the need for improved online course design to enhance interaction between students and teachers, as well as stronger student support to improve learning outcomes.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/educsci14111185/s1.

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Informed Consent Statement: All participants involved in the study gave their written informed consent, and the participants did not receive any financial compensation.

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education sciences

Article

Building a Sustainable Future: Investigating the Role and Contributions of Higher Education Institutions Instructors in Promoting Social Sustainability—Empirical Evidence from Ethiopia

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Abstract: The need for social sustainability through education is greater than ever. Despite numerous studies on this topic, there is still a gap in the research on the role and contribution of public higher education instructors in social sustainability. To address this, the researchers of this study conducted a study on the contributions of instructors in public higher education to social sustainability in Ethiopia. The study aimed to provide evidence for policy briefs and guide public universities. A quantitative method was employed, and the reliability of the structured questionnaire was tested using Cronbach's alpha. The data were analyzed by descriptive and inferential statistics. The findings revealed that 62.9% of instructors contributed to social sustainability, with significant predictors identified at 5%. Research and applied university instructors were 3.36 and 2.20 times more likely, respectively, to contribute compared to comprehensive universities. Furthermore, the results indicated that females were 0.64 times less likely to participate compared to males. Instructors who were optimistic about research implementation were 4.9 times more likely to engage, and those indicating "probably yes" were 18.5 times more likely as compared to the reference category. Educators involved in multiple roles were 0.13 times less likely to contribute than those focused solely on teaching. Ethiopia's Ministry of Education and university leaders should support female teachers and master's-level faculty at applied and comprehensive universities.

Keywords: sustainable development; social sustainability; higher education; instructors' roles and contributions; chi-square test of association; binary logistic regression model

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1. Introduction

In a time marked by increasing global challenges, sustainable development has become a fundamental goal for societies worldwide. Sustainable development aims to fulfill the needs of the current generation without compromising the ability of future generations to meet their own needs. Hence, pursuing economic growth, environmental sustainability, and social equity is crucial. The United Nations' Sustainable Development Goals (SDGs) emphasize the immediate requirement for initiatives that support peace, safeguard the environment, and advance prosperity for everyone, especially in developing areas such as Sub-Saharan Africa [1–3]. In the global pursuit of a sustainable future, sustainable development is a global goal aimed at meeting the needs of current and future generations without jeopardizing future generations' ability to meet their own needs. Thus, it is essential for the well-being of global society [4–7]. Sustainable development is a multifaceted concept that encompasses economic, environmental, and social dimensions. The integration of these elements is essential to achieve holistic and long-lasting progress [6–9]. The Sustainable Development Goals are particularly relevant in the context of developing countries, emphasizing eradicating poverty, protecting the environment, and ensuring peace and prosperity for all by 2030 [5]. Achieving these goals necessitates collaborative efforts across different sectors and a steadfast dedication to sustainable practices at all levels of society. Social sustainability is essential to sustainable development and promoting well-being and inclusiveness within communities [10]. It aims to cultivate inclusive societies, empower individuals, and strengthen community resilience and peace, ultimately fostering an improved quality of life for all [11,12].

The concept of social sustainability is multi-dimensional, encompassing active social participation, the promotion of social cohesion, the avoidance of social exclusion, and the encouragement of public engagement. It is not merely about existence but about ensuring a flourishing and enhanced quality of life [10,11]. It also involves expanding opportunities for everyone now and in the future [9]. Social sustainability is essential for establishing fair and equitable societies that are sustainable in the long run. It has the unique capacity to manage and influence both the positive and negative impacts of systems, processes, organizations, and activities on people and social life [13]. Social sustainability often receives less attention than economic and environmental sustainability despite its significance [14]. In recent decades, there has been a predominant emphasis on economic and environmental sustainability, neglecting the social dimension. Addressing this trend and adopting a more balanced and comprehensive approach to sustainable development is essential [4,15].

Higher education institutions that incorporate high-level professionals may play pivotal roles in addressing this imbalance. Higher education institutions play a crucial role in promoting social sustainability by empowering students with the knowledge and skills to make meaningful contributions to society. They are instrumental in fostering sustainable social development by imparting the requisite knowledge, skills, and attitudes that enable students to impact society positively [16]. The relationship between higher education and communities is vital for social, economic, and cultural progress [17]. Universities are responsible for shaping students' viewpoints, readying them for their future careers, and providing them with lifelong learning skills [18]. Despite criticism for not actively participating in significant social and economic issues, higher education institutions still play a crucial role in attaining social and economic goals [19]. Therefore, it is essential to enhance the role and impact of higher education in and on fostering social sustainability for the betterment and progress of society. Most studies have primarily focused on the role of higher education in the economic and environmental aspects of sustainable development, often neglecting its vital social dimension. The intersection of cultural heritage, economic progress, and social unity underscores the crucial role of higher education educators in guiding society toward excellence and sustainability. While economic and environmental development initiatives are undoubtedly important, focusing on sustainable social development is essential to promoting social stability and inclusive development [6]. This helps create inclusive, stable, resilient, and peaceful communities that can solve problems in difficult situations, build a knowledge base, and lead sustainable development.

The urgent need to prioritize social sustainability through higher education is emphasized by the increasing global challenges of violence, civil war, and societal unrest in today's world [20]. Education, particularly higher education, is crucial in addressing these challenges. The higher education system should emphasize cultivating its students' characters, competencies, values, justice, trust, truth, and intellectual virtues, including humility, curiosity, open-mindedness, and courage. Teachers play a vital role in building a more equitable, fair, and sustainable society [21,22]. They are also vital to establishing societal norms and values, generating new knowledge, and raising sustainability awareness for the future. They should focus on empowering individuals, building social cohesion, and advocating for sustainable community practices [17,23]. This research uses social capital theory and ecological systems theory to examine the impact of higher education instructors in Ethiopia on advancing social sustainability. Social capital theory underscores the significance of educational institutions in nurturing community engagement and political involvement through established networks, which are vital for cultivating social unity [24,25]. This study is in line with the theory as it explores the impact of educators on social cohesion, promoting social sustainability, and identifying the factors that affect their influence. Furthermore, Bronfenbrenner's ecological systems theory offers a valuable framework for understanding, at multiple levels, the diverse influences of the role of education in advancing social sustainability [26,27]. By exploring these diverse levels, this research sheds light on how educators interact with community and organizational networks, thus playing a vital role in promoting social sustainability in various settings. This integrated theoretical approach provides a comprehensive framework for assessing the varied impacts of public higher education instructors on social sustainability in Ethiopia. Ethiopia, located in the Horn of Africa, is a diverse and multicultural nation with a population of 117 million and an annual population growth rate of 2.5% [9]. The predominant religions are Ethiopian Orthodox Christianity, and the official language is Amharic. The country comprises over 90 distinct ethnic groups and 80 spoken languages [28]. Since 2019, the Ethiopian government has undertaken the remarkable initiative of planting more than 26 billion trees to preserve the environment, ensure the nation's economic sustainability, restore degraded lands, increase forest cover, and mitigate the impact of climate change [6,29,30]. The government is committed to implementing political reforms, achieving sustainable economic, social, and environmental development, and leading the nation toward prosperity to elevate Ethiopia to a middle-income country by 2025. However, Ethiopia is experiencing severe social, economic, and political issues, including civil war, political unrest, social upheaval, internal and external displacement, and financial challenges, such as inflation and those introduced through drought [31]. This situation has resulted in the nation continuing to struggle with significant issues, including over 1.3 million casualties and the displacement of more than 25 million people, positioning Ethiopia as one of the countries with the largest internally displaced populations [32,33]. Ethnic tensions, violent crime, civil disturbances, and localized threats create a complex security environment [34,35]. The Armed Conflict Location and Event Data Project reported 191 violent incidents in the region, resulting in 581 fatalities, underscoring Ethiopia's ongoing volatility [36,37]. Education aims to develop knowledgeable, autonomous, and socially integrated individuals, thereby contributing to societal and economic productivity, as well as effective political leadership [38]. Hence, higher education institutions that cultivate skilled professionals across various disciplines while emphasizing their social responsibility are vital in promoting social sustainability. They serve as catalysts for fostering civic engagement and exemplars of a harmonious society, mirroring the larger community on a smaller scale. Academicians play a significant role in maintaining social sustainability through their contributions to research, teaching, problem-solving, and participating in community [39]. The higher education sector in Ethiopia consists of 46 public universities and over 37,806 instructors with at least a master's or PhD [40–42]. This represents a substantial resource for addressing the nation's complex challenges. However, Ethiopian universities grapple with significant social and political issues, contributing to broader societal issues. Hence, to address this gap, researchers have emphasized the critical need for research on the role and contributions of higher education instructors in promoting social sustainability in Ethiopia.

The primary aim of this research is to examine the contribution of higher education instructors in Ethiopia regarding their role and responsibility in promoting social sustainability. Specifically, the study objectives are to identify higher education instructors' awareness and understanding of their responsibilities and devotion to their commitment, assess the extent of instructors' contributions to social sustainability, and identify the variables that affect the contribution of higher education instructors to social sustainability and the existence of a substantial relationship between these variables. Through addressing these objectives, this research aims to offer valuable insights into the practical and theoretical implications of higher education's role in promoting social sustainability.

This study's significance extends beyond academic discourse. It offers practical implications for Ethiopia's policymakers, educators, and community leaders, emphasizing the need for integrated approaches in the education sector to drive social change and sustainability. The findings underscore the pivotal role of education, particularly higher education instructors, in shaping a sustainable future. These insights can guide policymakers, the Ministry of Education, and higher education institutions in effectively leveraging the knowledge and skills of instructors for social sustainability.

The significant contributions of this article are mentioned as follows:

(1) The first significant contribution of this article is its comprehensive evaluation of instructors' understanding of their pivotal role in conducting research on social sustainability within the field of education. This critical assessment not only addresses pressing challenges but also recognizes the importance of their role. It underscores how fostering a sustainable educational environment is integral to achieving long-term economic development and advancing human resource capabilities.

(2) It also assesses the extent of instructors' contributions to social sustainability at public universities in Ethiopia, highlighting how these efforts engage instructors actively in research, research-based community service, and the advancement of educational programs. This recognition of their active involvement can serve as a source of motivation for further engagement.

(3) This study also significantly contributes by identifying critical variables for social sustainability, providing valuable insights for the government, decision-makers, and the Ministry of Education to address challenges using a scientific, evidence-based approach.

(4) Furthermore, this article makes an essential contribution by expanding knowledge on social sustainability in higher public universities. It offers insights globally and specifically within the context of Ethiopia.

The article is organized as follows: Section 2 covers the materials and methods, including data collection and analysis procedures. Section 3 presents the empirical findings, and Section 4 discusses these findings within the context of the existing literature. Section 5 concludes with remarks and recommendations for future research and practical applications.

2. Materials and Methods

2.1. Quantitative Research Method

The primary objective of this research is to examine the contribution of higher education instructors in Ethiopia to promoting social sustainability. Specifically, this study aims to identify higher education instructors' awareness of their role and responsibilities and their devotion to these responsibilities, assess the instructors' contributions to social sustainability, and identify the variables that affect the contribution of public higher education instructors to social sustainability, along with exploring the existence of substantial relationships between these variables.

The researchers employ quantitative research methods to achieve these objectives, which involve collecting and analyzing numerical data. Quantitative research offers a structured and objective methodology for measuring and analyzing data, providing a robust basis for conclusions. This approach is indispensable for identifying correlations between variables and generating broad-applicability predictions [43]. With large sample sizes and rigorous statistical analyses, quantitative research amplifies the capacity to extrapolate findings to diverse educational contexts, rendering them applicable to broader populations [44]. It provides an in-depth initial understanding of the research problem by analyzing quantitative data, which lays the groundwork for further investigation [45,46]. It also forms the foundation for making data-informed decisions based on empirical evidence [47]. Moreover, this method facilitates establishing distinct groups or categories based on empirical data, thereby enabling a more targeted exploration of specific phenomena or subgroups within the population [48,49]. Furthermore, the quantitative method is valued for acknowledging and measuring objective realities within one particular context [50]. Hence, this study employs this method to produce robust and actionable insights informing practitioners, policymakers, and stakeholders about the roles and contributions of public higher education institution instructors in promoting social sustainability. Also, we aim to acknowledge and measure the objectives of realities from an Ethiopian instructor's perspective. In addition, we seek to identify correlations between various variables and generate broad-applicability predictions. Moreover, this study provides an initial understanding of instructors' roles and contributions to social sustainability by analyzing quantitative data, which lays the groundwork for further investigation and a foundation for making data-informed decisions based on empirical evidence.

2.2. Data Gathering Tools

The study utilized structured questionnaires obtained from instructors in public higher education.

2.3. Questionnaires

In this work, we conducted a structured questionnaire to collect important variables that are useful for effective decision-making and policy briefs [51]. They are helpful, in various situations, for gaining insights into instructors' attitudes and understanding toward social sustainability in the education sector. Researchers can efficiently gather extensive data sets from diverse respondents, enabling statistical analysis and subgroup comparisons, especially when dealing with large and diverse sample sizes [52].

Consequently, the researchers utilized closed-ended and structured questionnaires to quantitatively gather information from higher education instructors and understand their perspectives. To ensure the validity and reliability of the data, the researchers conducted a pilot study. They utilized Cronbach's alpha coefficient to assess the closed-ended questionnaire items, examining instructors' contributions to social sustainability.

2.4. Reliability Test

Before administering the questionnaires, the researchers tested the reliability of the variables. This study collected primary data from instructors from higher education institutions using closed-ended questionnaires. The reliability of the variables was evaluated using Cronbach's alpha, resulting in high reliability with scores exceeding 0.70 for all variables and a general score of 0.94.

2.5. Sampling Procedures and Scientific Sample Size Determination

Stratified Random Sampling Procedures

In this work, we assessed all the prominent public universities in Ethiopia and categorized them according to the Ministry of Education's recent classification. This categorization formed the basis of our stratification approach. We have included a diagram depicting the university selection process (refer to Figure 1).

Then, we utilized a simple random sampling technique with a stratified random sampling procedure to select instructors from each university in proportion. We assumed instructors within the same university to be homogeneous and those instructors between universities to be heterogeneous. Our approach involved defining three strata: the first stratum encompassed all instructors in applied universities, the second included instructors in research universities, and the third consisted of instructors in general or comprehensive universities.

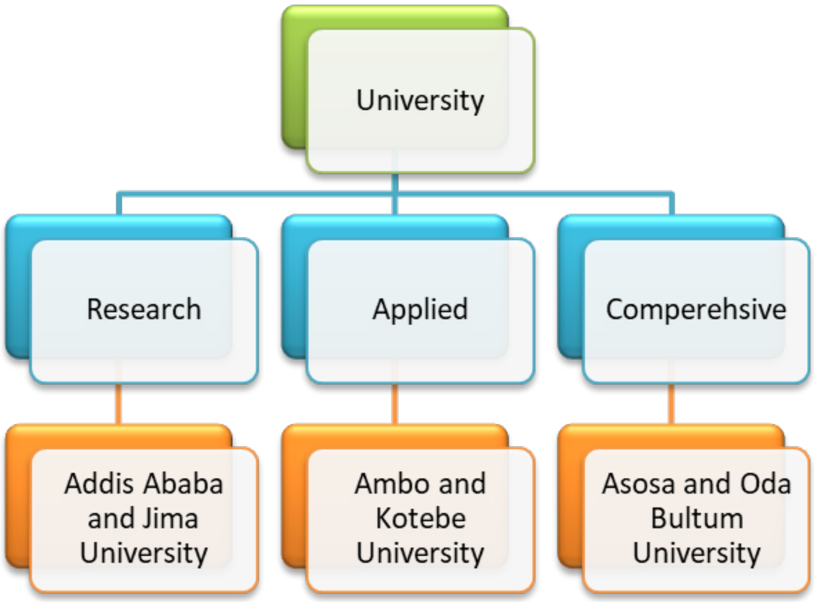

Figure 1. Sampling procedures at public higher education institutions in Ethiopia.

2.6. Scientific Sample Size Determination

When dealing with categorical data and employing stratified sampling procedures, it is highly advisable to use scientifically determined sample sizes based on the method described by [53]. Therefore, the sample size formula used in this study was examined using stratified random sampling to determine proportions at a 95% confidence level. This formula is calculated based on the sample size for this study [53].

$$n = \frac{Z^2 \cdot p \cdot q}{e^2} \tag{1}$$

where:

- n = the total sample size to be achieved through the formula;
- Z = the Z-score corresponding to the desired confidence level;
- p = the estimated proportion of instructors involved in the contribution;
- q = 1 − p not involved;
- e = the allowable margin of error.

For a 95% confidence level, where $Z = 1.96$, $p = 0.5$, $q = 0.5$, and $e = 0.05$, the calculation is:

$$n = \frac{(1.96)^2 \cdot 0.5 \cdot 0.5}{(0.05)^2} \tag{2}$$

Substituting the values:

$$n = \frac{(1.96)^2 \cdot 0.5 \cdot 0.5}{(0.05)^2} = \frac{3.8416 \cdot 0.25}{0.0025} = 384 \tag{3}$$

where p is the probability that instructors contributed to social sustainability in previous work, and q denotes the likelihood of those who were not involved. Due to the scarcity of literature in this area, the researchers considered an equal likelihood for each, at 50%. We considered a 15% non-response of the sampling, including a 5% allowable margin of error. The total sample obtained was 460 instructors. We distributed the questionnaire for the 460 samples through Qualtrics software's online institutional emails to the instructors, of which only 10 still needed to complete the survey.

2.7. Variable Identification

Researchers identified the variables as dependent and independent, as outlined below.

2.7.1. Dependent Variable

The dependent variable in this study is the contribution of instructors to social sustainability. Let Y be the response variable, where Y equals 1 if instructors contribute to social sustainability at public higher education institutions in Ethiopia and 0 if not.

2.7.2. Independent Variable

Based on the literature review, we identified the predictor variables responsible for instructors' contributions to social sustainability in Ethiopian, public higher education institutions. These include socio-demographic variables such as gender, educational qualification, university category, experience, and several items related to social sustainability.

2.8. Operational Definitions of Key Words

Sustainable development:

Meets the needs of the present generation without compromising the ability of future generations to meet their needs.

Social sustainability:

Promotes social stability and cohesion, fostering inclusive, resilient societies where citizens have a voice, governments address systemic inequalities, and individuals drive solutions.

Social stability:

Refers to a stable and conducive environment where people can live together peacefully, an essential aspect of social sustainability.

Higher education institution:

University.

Instructors:

Academic staff of universities/higher education institutions.

Instructor roles and responsibilities:

Academic staff duties (teaching–learning, problem-solving research, and research-based community service).

Instructor contributions:

Engagement/involvement/participation.

2.9. Data Analysis Method

In this article, we employed both descriptive and inferential statistics. Descriptive statistics, such as frequency distributions, graphs, and diagrammatic data presentations, were used to provide an overview of the data. However, since descriptive statistics alone cannot be used to conclude policy briefs and decision-making, we also utilized inferential statistics. First, we conducted a chi-square test of association to filter out predictor variables that were not associated with contributions to social sustainability. Following this, we employed a binary logistic regression model to identify which categories of variables impact the contribution of instructors to social sustainability at higher public institutions. The overall goodness of fit was verified using a model summary, specifically Nagelkerke R-squared.

3. Results

In this section, we present the results of our study based on the dataset collected through a structured questionnaire. Before conducting an in-depth analysis, we check the reliability issue through Cronbach's alpha and confirm that the data are highly reliable.

Then, we provide descriptive statistics to give an overview of the demographic characteristics of the respondents, instructors' awareness of their responsibilities, and the concept of social sustainability. We will also analyze which responsibilities they devote more time and knowledge to. Following this, we will present the results of our work using inferential statistics focusing on a chi-square test of association to look at the relationships between the predictor variables and social sustainability contributions. Lastly, we will identify which categories of each predictor variable most significantly influence contributions to social sustainability in public higher education institutions in Ethiopia. Finally, we will present the results of the model summary using various statistical methods to assess our model's overall fit and explanatory power.

- Socio-Demographic Characteristics of Respondents

A descriptive analysis of this study shows that the questionnaire was distributed to 460 instructors: 450 filled out and finished the survey, where 335 (74.4%) were males and 115 (25.6%) were females. The qualifications of the respondents were as follows: 277 (61.6%) MA/MSc and 173 (38.4%) PhD and above. An analysis of the categories of the universities shows that 200 (44.4%) instructors from research universities, 146 from applied universities (32.4%), and 104 from comprehensive universities (23.1%) participated in this study.

The results related to the experience of the instructors show that 26 (5.8%) instructors have 1–5 years' experience, 127 (28.2%) instructors have 6–10 years' experience, 141 (31.3%) instructors have 11–15 years' experience, 96 (21.3%) instructors have 16–20 years' experience, 53 (11.8%) instructors have 21–25 years' experience, and 7 (1.6%) instructors have 26 year's or more experience. The data show that most of the instructors in the study were male instructors with a master's degree and 11–15 years of teaching experience. Finally, a greater number of research university instructors participated in social sustainability than instructors from applied and comprehensive universities (see Table 1).

Table 1. A summary of the results based on the socio-demographic characteristics of the respondents.

Variables	Category	Frequency	Percentage
University category	Research University	200	44.44%
	Applied University	146	32.44%
	Comprehensive/General University	104	23.11%
	Total	450	100.00%
Gender	Female	115	25.56%
	Male	335	74.44%
	Total	450	100.00%
Educational level	MA & MSc	277	61.56%
	PhD and above	173	38.44%
	Total	450	100.00%
Work experience	1–5	26	5.78%
	6–10	127	28.22%
	11–15	141	31.33%
	16–20	96	21.33%
	21–25	53	11.78%
	26 and above	7	1.56%
	Total	450	100.00%

3.1. Higher Education Instructors' Role- and Contribution-Related Variables

The result shows that 420 (93.3%) instructors responded that they recognize they have teaching, research, and community service roles and responsibilities, and 30 (6.67%) responded that they have teaching and research roles and responsibilities.

Moreover, Figure 2 illustrates the significant roles and responsibilities prioritized by public higher education institution instructors. Among instructors from public universities, the majority (60.89%) focus primarily on teaching, while approximately 31.56% are dedicated to research, and 7.56% engage in research alongside community-based services. This study's results also describe instructors' allocation of time and expertise. A total of 274 respondents (60.9%) emphasized teaching roles, 142 (24.3%) balanced teaching with research responsibilities, and 34 (7.6%) were involved in teaching, research, and community service. These findings identified instructors' awareness and understanding of their roles and responsibilities and on which role and responsibility they give more focus.

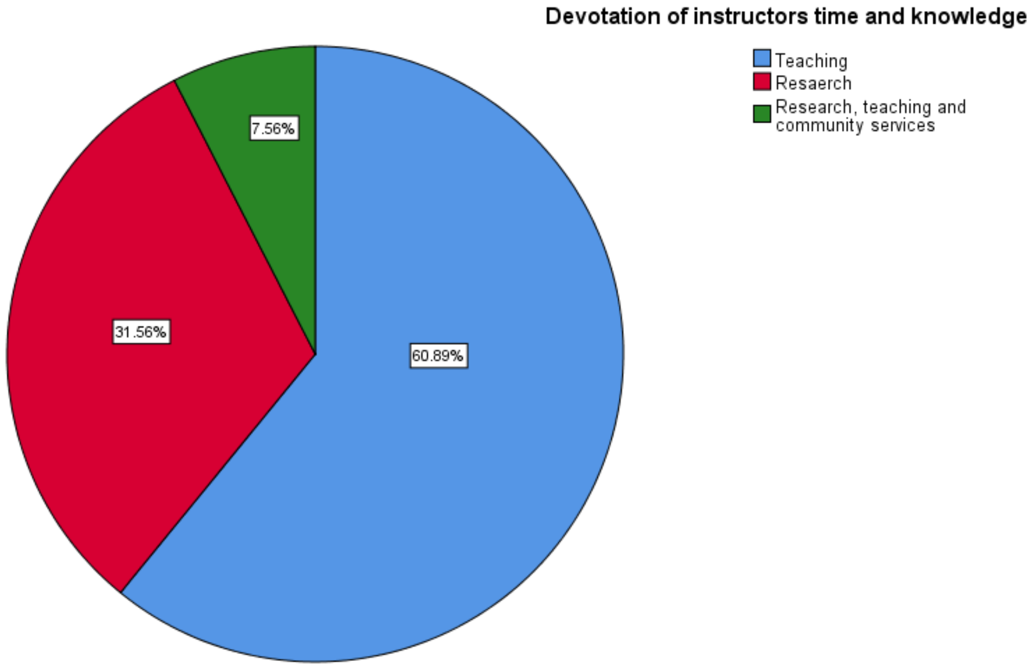

Figure 2. Devotion of instructors' time and knowledge in public higher education institutions in Ethiopia.

Figure 3 illustrates the level of engagement among instructors in social sustainability within Ethiopian public higher education institutions. Out of the 450 instructors analyzed, 62.9% were actively involved in contributing to social sustainability at the time of data collection. This indicates a significant expectation for universities and the Ministry of Education to mobilize faculty participation in these efforts. The figure also shows that 283 respondents (62.9%) believe that higher education instructors play a crucial role in fostering resilient, inclusive, and rational environments, while 167 (37.1%) do not share this belief. These findings highlight the perceived significant contribution of instructors to research and initiatives related to social sustainability in Ethiopian public higher education institutions.

Figure 4 illustrates the distribution of instructor experience in public higher education institutions in Ethiopia included in this research. The majority (31.33%) of instructors in higher public universities have 11 to 15 years of experience, followed by 29.22% with 6 to 10 years. Additionally, Figure 4 shows that 5.78% of instructors have 1 to 5 years of experience.

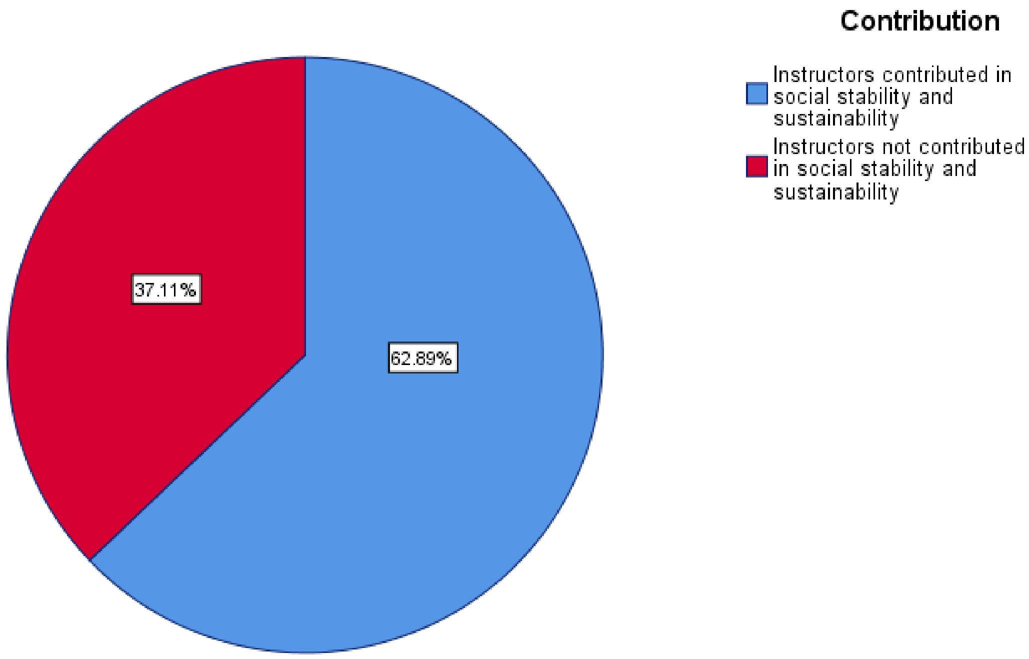

Figure 3. Level of instructor engagement in social sustainability in Ethiopian public higher education institutions.

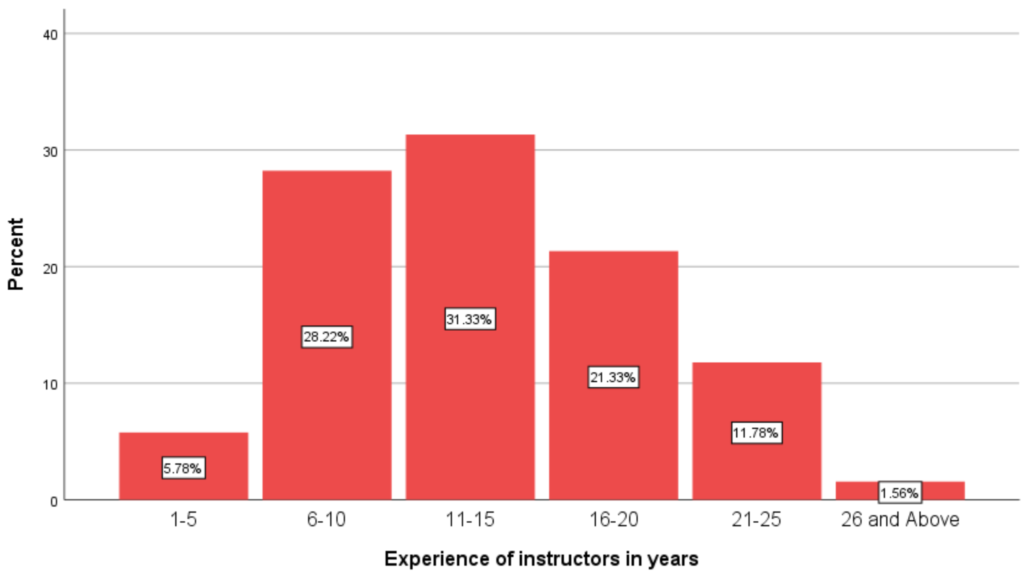

Figure 4. Instructors' experience in Ethiopian public higher education institutions in research, teaching, and community-based service engagement.

The results of this study based on the multiple bar charts highlight that 163 instructors holding master's degrees were not actively involved in contributing to social sustainability. In contrast, 169 instructors with PhD actively contributed to social sustainability in public higher education institutions in Ethiopia, as given in Figure 5. This suggests that PhD holders contributed more actively to social sustainability in Ethiopia than instructors with master's degrees.

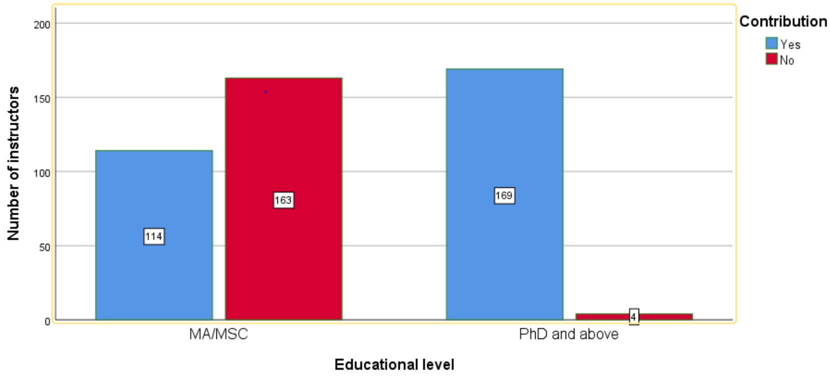

Figure 5. Level of instructors' social sustainability contributions by the qualifications.

In Table 2, the cross-tabulations reveal that the majority of instructors involved in research came from research institutions (200), followed by those from applied research institutions (146), and the fewest from general or comprehensive institutions (104). Table 2 presents the descriptive results of analyzing gender inequalities and variations between different types of universities, from which we can see that female involvement in research, applied, and comprehensive universities is low compared to males. Relatively, the number of female instructors in comprehensive universities is close to that of males, as compared to that of female instructors in research and applied universities in Ethiopia.

Table 2. Distribution of instructors by type of university and sex.

Sex	Research	Applied	Comprehensive
Female	23	45	47
Male	177	101	57
Total	200	146	104

Table 3 indicates the demographic data and understanding of the related variables, which indicates the contribution of the instructors to social sustainability by a set of predictor variables. Detailed results are provided in Table 3. When we compare university categories, the participation of female instructors in comprehensive universities is greater than that of applied and research universities. Regarding work experience, the highest number of years of service among instructors at public higher education institutions fell within the range of 11 to 15 years (141), while the least had over 26 years' experience (9) and the second lowest had 1 to 5 years' experience (26).

These data also indicate more male respondents (335) than female respondents (115). Interestingly, the cross-tabulation results suggest that males are more actively involved in contributing to social sustainability than females. Additionally, instructors from research institutes demonstrated higher engagement in social sustainability contributions than instructors from applied and general or comprehensive institutions.

Table 4 presents the descriptive results of variables related to the teaching activities of the 450 instructors from public higher education institutions in Ethiopia. Most instructors make moderate contributions to social sustainability through the teaching–learning process. Most instructors (279) did not empower their students to think critically and make informed decisions through teaching, with only four instructors indicating yes. The descriptive results indicate that instructors' contributions to fostering rational and resilient citizens—by teaching, encouraging, and advising students to celebrate and respect diversity, as well as supporting them in developing problem-solving skills—still remain low (see Table 4).

Table 3. Demographic- and understanding-related variables.

Variables	Category	Contribution		Total
		Yes	No	
University	Comprehensive	59	45	104
	Applied	70	76	146
	Research	154	46	200
	Total	283	167	450
Gender	Female	58	57	115
	Male	225	110	335
	Total	283	167	450
Qualifications	MA/MSc	114	163	277
	PhD and above	169	4	173
	Total	283	167	450
Work experience (years)	1–5	6	20	26
	6–10	60	67	127
	11–15	67	74	141
	16–20	90	6	96
	21–25	46	7	53
	26 or more	4	3	7
	Total	283	167	450
Understanding of role	Definitely not	58	20	78
	Probably not	97	69	166
	Might or might not	114	19	133
	Probably yes	8	39	47
	Definitely yes	6	20	26
	Total	283	167	450
Prioritization and devotion to role	Yes	89	65	154
	No	194	102	296
	Total	283	167	450

Table 5 presents the descriptive results of several research-based variables and their impact on social sustainability among instructors. The results show that instructors perceive extensive research efforts as crucial for advancing social sustainability within their institution or community and as significant in promoting peace and preventing conflicts. Additionally, the degree of research results significantly contributes to fostering inclusion and social cohesiveness. Finally, the impact of initiatives aimed at fostering social interaction, promoting cultural assimilation, and fostering harmony falls within the range of small to moderate, as presented in Table 5.

Similarly, this research presents the results of several predictor variables versus their contribution to social sustainability in Table 6. Instructors' contributions to community-based engagement initiatives to create a peaceful community range from small to moderate. The results for all community-based variables are presented in Table 6.

Table 4. Teaching-related variables.

Variables	Category	Contribution		Total
		Yes	No	
Empower their students to think critically and make informed decisions through their teaching	Small	4	279	283
	Moderate	9	150	159
	Great	4	8	8
	Total	283	438	450
Building rational and resilient citizens through teaching	Small	4	279	283
	Moderate	9	150	159
	Great	4	8	8
	Total	283	450	450
Encourage and advise students to celebrate and respect diversity while cultivating a harmonious atmosphere	Small	2	268	270
	Moderate	10	120	130
	Great	2	37	39
	Total	270	435	450
Supporting students in developing problem-solving skills	Small	2	269	271
	Moderate	8	131	139
	Great	10	28	38
	Total	271	428	450

Table 5. Research-related variables.

Variables	Category	Contribution		Total
		Yes	No	
The impact of research efforts on advancing social sustainability within their institution or community	Small	7	283	276
	Moderate	24	128	152
	Great	24	15	15
	Total	283	411	450
Extensive research findings play a crucial role in promoting peace and preventing conflicts	Small	132	151	283
	Moderate	167	7	160
	Total	299	151	450
The degree of research results significantly contributes to fostering inclusion and social cohesiveness	Small	20	263	283
	Moderate	129	38	167
	Total	149	301	450
Extensive research is vital to addressing and contributing to social, economic, and political	Small	148	134	282
	Moderate	167	7	160
	Great	315	1	1
	Total	450	450	450
The impact of initiatives on fostering social interaction, promoting cultural assimilation, and fostering harmony	Small	72	211	283
	Moderate	155	12	167
	Total	227	223	450

Table 6. Community-service-related variables.

Variables	Category	Contribution		Total
		Yes	No	
Engaging in community service initiatives to create a peaceful community	Small	94	189	283
	Moderate	167	7	160
	Total	261	189	450
Participation in the community is essential to making a positive impact and contributing to the betterment of society	Small	52	216	268
	Moderate	160	7	167
	Great	7	8	15
	Total	227	223	450
Take initiative in social interaction and cultural promotion	Small	72	211	283
	Moderate	155	12	167
	Total	227	223	450
Identifying and solving local community problems	Small	73	209	282
	Moderate	122	45	167
	Great	1	0	1
	Total	195	254	450
Enhancing conflict resolution and peacemaking skills in the community	Small	38	245	283
	Moderate	160	7	167
	Total	205	245	450
Engaging in civic activities to promote civic engagement	Small	142	139	281
	Moderate	160	7	167
	Great	1	1	2
	Total	309	139	450
Participating in local community collaboration with government agents	Small	123	160	283
	Moderate	160	7	167
	Total	290	160	450

Figure 6 presents descriptive results on the devotion of instructors' time and knowledge to their roles and responsibilities in public higher education institutions, examining their contributions to social sustainability in Ethiopia, from which we note that instructors who are highly involved in all duties are less engaged in contributing to social sustainability in public higher education institutions. The results also show that the proportion of instructors who are involved in contributing to social sustainability is almost similar. This result indicates that a tremendous amount of work is expected of public higher education instructors to be engaged in social sustainability research.

The data in Figure 7 presented in the box plot reveal an unexpected distribution concerning social sustainability. This indicates unequal participation among public higher education institution instructors in social sustainability across different university categories based on qualifications. Consequently, transforming a categorical variable into a continuous one for use in a classical linear regression model is not recommended. Instead, it is advisable to employ appropriate statistical tools, such as the chi-square test of association and the logistic regression model for such phenomena.

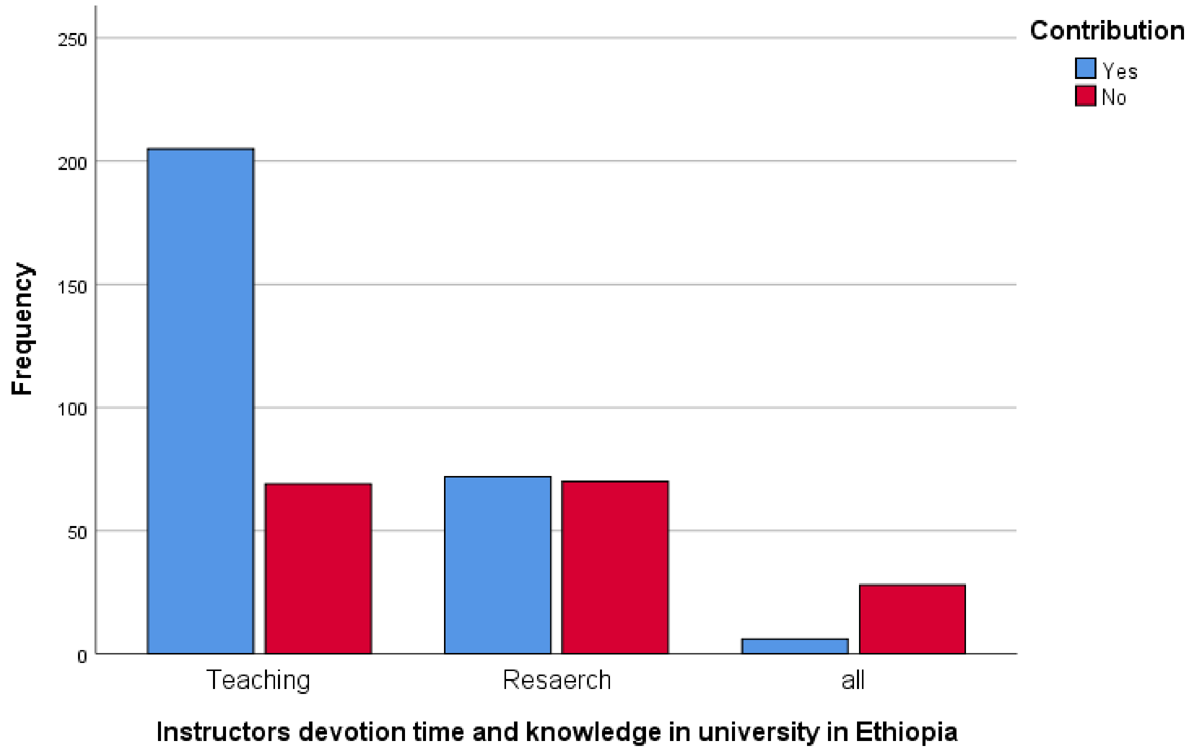

Figure 6. Instructors' contributions in Ethiopian public higher education institutions.

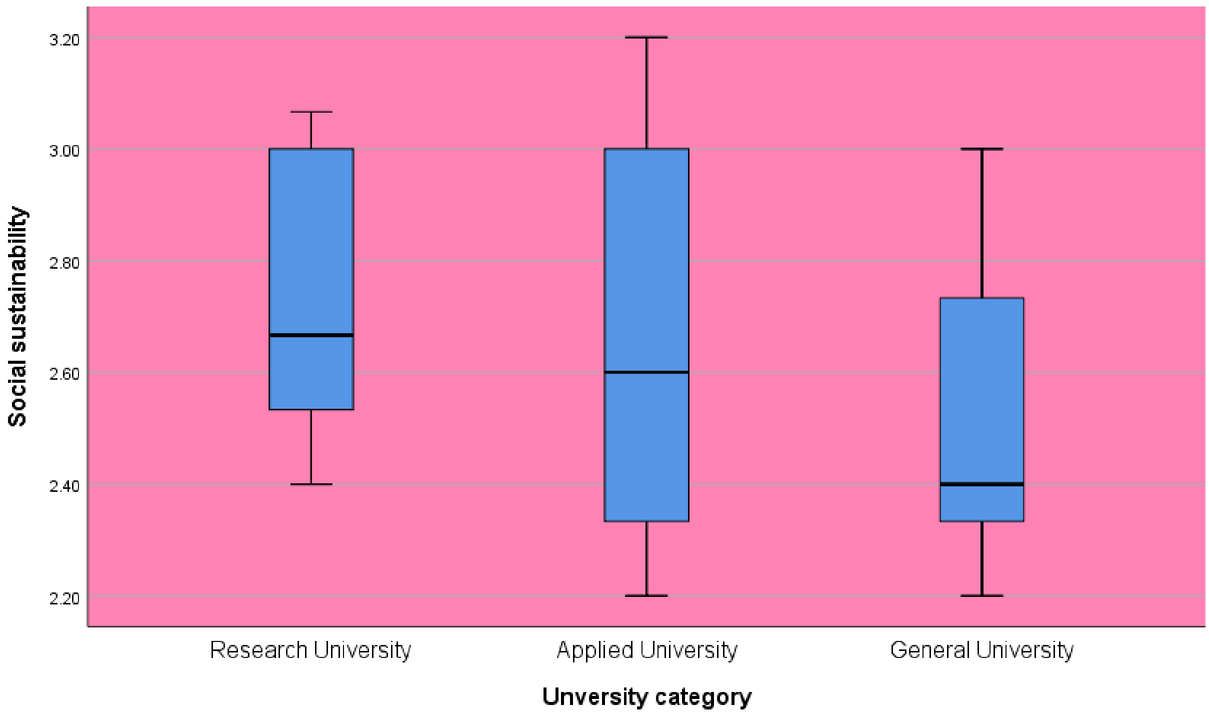

Figure 7. Box plot of social sustainability by university category in public higher education institutions.

Before applying the binary logistic regression model to determine which categories of variables have the most significant influence on teachers' contributions to social sustainability, it is essential first to establish if there is a statistically significant association between a set of predictor variables and the response variable measuring the contribution to social sustainability. This section examines the association between the dependent variable (social sustainability) and each independent variable (instructors' contributions). This was performed by evaluating the association using the chi-square association test and cross-tabulating each independent variable against the dependent variable. In addition, the frequency distributions of each category of independent variables were analyzed. The results show that all predictor variables were statistically significantly linked to the response variable, except social sustainability. Therefore, the findings underscore a statistically significant relationship between predictor variables, including university category, gender, qualifications, work experience, all factors, and the impact of instructors on social sustainability, at a 5% significance level (Table 7).

The Pearson chi-square test was utilized to examine the relationship between a group of predictor variables and the dependent variable of instructors' sustainability at a significance level of 5%. Table 7 shows a statistically significant association between predictor variables, including university category, gender, qualifications, work experience, roles and responsibilities of instructors, and instructors' prioritization and devotion to their roles and responsibilities, all other items presented in Table 7, and instructors' contributions to social sustainability, at a 5% significance level.

Table 7. Instructors' contributions to social sustainability versus a set of predictors.

Variables	Value	Degrees of Freedom	*p*-Value
University category	32.72	2	0.000
Gender	10.27	1	0.001
Qualifications	145.83	1	0.000
Work experience	163.71	5	0.000
Implementation of research findings	95.52	4	0.000
Conducting research	2.61	1	0.106
Understanding roles and responsibilities	28.20	1	0.000
Prioritization and devotion to the role	55.56	2	0.000
Empower students to think critically and logically	16.04	2	0.000
Building rational and resilient citizens through teaching	16.04	2	0.000
Persuade students to celebrate and respect diversity	99.39	2	0.000
Encourage students to minimize conflict-creating issues	33.71	2	0.000
Supporting students in developing problem-solving skills	29.68	2	0.000
Impact of research efforts on advancing social sustainability	72.36	2	0.000
Impact of findings on promoting peace and preventing conflicts	134.11	1	0.000
Impact of research on creating inclusive and social cohesiveness	233.54	1	0.000
Impact of research on addressing social, economic, and political issues	113.81	2	0.000
Impact of promoting the cultivation of rational and conscientious citizens	158.05	2	0.000
Involvement in community service contributions	192.29	1	0.000
Engaging in community service initiatives to create a peaceful community	252.79	2	0.000
Impact of initiatives on social interaction and cultural promotion	190.70	1	0.000
Identifying and solving local community problems	95.66	2	0.000
Enhancing conflict resolution and peace-making skills in the community	317.36	1	0.000
Engagement in civic activities to promote civic engagement	121.17	2	0.000
Participating in local community collaboration with government agents	146.51	1	0.000

3.2. Binary Logistic Regression Model

In this article, beyond looking at the test of association between a set of predictor variables and response variables, as mentioned above, we also employed a binary logistic regression model to see the magnitude of the impact of each category of predictor variable on contributions to social sustainability in higher education institutions in Ethiopia. First, we checked the goodness of fit using the Hosmer and Lemeshow goodness of fit to evaluate the model's suitability with the data. This study's findings demonstrated that the model fits the data reasonably well. Among all of the predictor variables examined in the survey, nearly six were statistically significantly correlated with a contribution to social sustainability at a 5% significance level.

The study results indicate that faculty members in research universities are 3.4 times more likely to contribute to social sustainability research than those in comprehensive universities. Likewise, educators affiliated with applied universities are 2.2 times more likely to contribute to social sustainability compared to those in the reference category of comprehensive institutions within higher public institutions. The result of the logistic regression model pinpoints that staff in research institutes are more involved in contributing to social sustainability in public higher education institutions in Ethiopia. Furthermore, the results suggest that females are 0.642 times less likely to engage in social sustainability research than their male counterparts, indicating a higher engagement of males within higher public institutions in Ethiopia. This highlights that males are more involved in social sustainability research in higher education in Ethiopia. In addition, instructors who are optimistic about the potential implementation of research findings from public higher education institutions to address societal challenges are 4.857 times more inclined to participate in social sustainability research than those who firmly believe such implementation will not happen. Furthermore, instructors who indicated a likelihood of probably yes are 18.553 times more inclined to engage in social sustainability research than those who responded probably not, at a 5% level of significance with a confidence level of 95%. On the other hand, educators who are engaged in all roles are 0.132 times less likely to contribute to social sustainability than those solely focused on teaching, at a significance level of 5%. Conversely, teachers who dedicate themselves to all roles are 13.865 times more likely to contribute to social sustainability than those involved only in teaching. Lastly, teachers who concentrate on research alone are 2.888 times more likely to be involved in social sustainability than those solely focused on education, at the same significancelevel (see Table 8).

The estimation of regression coefficients, in conjunction with their standard errors, is used to calculate the Wald statistic, which signifies the significance of the predictor variable within the model. The odds ratio is displayed in Table 9 based on the model summary. Cox–Snell R-squared and Nagelkerke R-squared serve as pseudo-R-squares for evaluating the model's overall fit (found in the -2 log-likelihood statistic in Table 9). With a Cox and Snell R-squared value of 0.715, we observe that the predictor variables account for 71.5% of the variation in the dependent variable. Conversely, the Nagelkerke R-squared value of approximately 97.6% suggests that the predictor variables explain nearly all the variation in the dependent variables. After constructing the binary logistic regression model, it is essential to gauge the proportion of influence that the predictor variables have on social sustainability contributions using the Nagelkerke R-squared. The model summary demonstrates that the collective impact of predictor variables on social sustainability is 97.6%. This high percentage indicates that this study encompasses the most pertinent and influential variables affecting social sustainability contributions among teachers in public higher education institutions. Our model effectively captures the factors influencing social sustainability contributions, demonstrating a solid fit for the data (Table 9).

Table 8. Binary logistic regression model findings significantly associated with instructors' contribution to social sustainability.

Parameter	Category	B	S.E.	Wald	df	Sig.	Exp(B)
University Category	Comprehensive			25.818	2	0.000 **	
	Research	1.212	0.240	25.516	1	0.000 **	3.359
	Applied	0.790	0.272	8.446	1	0.004 **	2.204
Gender	Males: Ref						
	Females	−0.443	0.235	3.551	1	0.040 **	0.642
Qualification	PhD: Ref						
	MSc	−4.10	0.52	62.11	1	0.000 **	0.017
Experience (years)	1–5						
	6–10	−18.76	6775.99	0.000	1	0.99	0.000
	11–15	−18.09	6775.99	0.000	1	0.99	0.000
	16–20	−53.65	8213.65	0.000	1	0.99	0.000
	21–25	−40.01	8519.37	0.000	1	0.99	0.000
	26 or more	−40.02	16,047.22	0.000	1	0.99	0.000
Perception	Definitely not			35.14	4	0.000 **	
	Probably not	1.58	0.39	16.06	1	0.000 **	4.86
	Might or might not	0.35	0.43	0.68	1	0.41	1.42
	Probably yes	2.92	0.56	27.45	1	0.000 **	18.55
	Definitely yes	17.47	3134.79	0.000	1	0.99	387.79
Sustainability	No	−1.04	0.31	11.30	1	0.001 **	0.352
Understanding	Teaching, Res., and CS	−2.02	0.44	21.59	1	0.000 **	0.132
Devotion to Roles	Teaching						
	Research	1.06	0.22	23.67	1	0.000 **	2.89
	Community Service						
	All	2.63	0.471	31.177	1	0.000 **	13.87

** Teaching, Res., and CS denotes teaching, research, and community service.

Table 9. Likelihood and pseudo-R-squared.

−2 Log Likelihood	Cox–Snell R-Squared	Nagelkerke R-Squared
28.510	0.715	0.976

4. Discussions

This article comprehensively assesses the variables associated with the role and contribution of higher education instructors in promoting social sustainability based on empirical evidence from Ethiopia. This study presents the results based on datasets to achieve this objective. Firstly, descriptive statistics are provided to give an overview of the demographic characteristics of the respondents and the instructors' understanding of their roles and responsibilities, an analysis of which responsibilities they devote more time and knowledge to, and the extent of instructors' contributions to social sustainability. The results were then presented using inferential statistics and the chi-square association test to examine the relationships between the predictor variables and social sustainability contributions. Lastly, the study identified which categories of each predictor variable most significantly influenced contributions to social sustainability in higher public institutions in Ethiopia. Additionally, the results of the model summary were presented using various statistical methods to assess the model's overall fit and explanatory power. Subsequently, this study was further analyzed using the binary logistic regression model to infer the magnitude of the impact of each category of predictor variable on contributions to social sustainability compared with the reference category. In this section, the study's findings are thoroughly discussed over the state of the art, ensuring a rigorous and reliable analysis. Higher education instructors (HEIs) are responsible for teaching and learning, conducting research, and providing community services [18,29,54]. Academicians play a vital role in research, teaching, and problem-solving, contributing to academic, social, and humanitarian spheres [39]. Their responsibilities extend to individuals, institutions, and society, as outlined in Ethiopia Higher Education Proclamation No. 650/2009 [55]. Furthermore, Ethiopia's higher education system aims to produce competent, skilled, and mature graduates. Higher education faculty members are accountable for educating students to become competent citizens, conduct research, and provide community services, emphasizing their responsibility to individuals, institutions, and society [56,57]. However, the results of our study showed that 274 instructors (60.9%) indicated that most of their time and knowledge are spent on teaching roles, 142 instructors (24.3%) spend most of their time on teaching and research roles, and 34 instructors (7.6%) spend most of their time on teaching, research, and community service roles. The results indicate that 274 instructors (60.9%) neglect research and community service responsibilities, devoting their time and knowledge primarily to teaching responsibilities. Our finding is more consistent with the work of [58], who emphasized that government and university coordination tends to prioritize research over teaching, highlighting the need for social and cultural change. However, teachers prioritize teaching. Moreover, Rieckmann (2012) [59] also addressed that higher education institutions need to adapt their roles and responsibilities to address global change and the complexity of future professionals' work to ensure they can tackle sustainable development issues and address social, local, and cultural particularities. Therefore, instructors need to be actively and equally involved in research and community-based services in higher public universities in Ethiopia that are similar to the teaching. The government and the Ministry of Education should encourage and motivate instructors to shift their focus from teaching to conducting scientific research and community-based services that promote social sustainability. This study also provides an in-depth analysis of public higher education instructors' contributions to social sustainability in Ethiopia. The results showed that 62.9% of instructors believed that they contributed to social sustainability, while 37. 1% were not involved in contributing to social sustainability in higher public institutions in Ethiopia. Our results are more aligned with those of [60,61], which indicated that many universities still need to be more effective than companies in contributing to advancing sustainable societies. Additionally, João et al. (2022) [62] conducted research in Ethiopia and suggested many practical experiences and solid research on approaches that effectively engage professional educators within education for sustainable development. Moreover, universities should focus on achieving enlightenment—human development and liberating society from ignorance, irrationality, mental colonialism, and ecosystem health [63]. In Ethiopia, higher education institutions have an opportunity and a growing necessity to maintain and advance a new, proactive, and responsive approach to meet the nation's and its citizens' requirements by producing qualified graduates and conducting pertinent research and studies [64]. Hence, by effectively and efficiently using a highly skilled workforce, higher education institutions should contribute to social sustainability that leads to the country's sustainable development. The result of this study revealed that university category, gender, qualifications, and work experience, including variables related to social sustainability given in Table 3, are statistically significantly associated with the instructors' contributions to social sustainability, at a 5% significance level. This finding is more consistent with research conducted by [65], indicating that the university category is statistically associated with instructors' contributions to social sustainability.

Similar to the authors of [66], which indicates that sex and academic affiliation are an important, influential factor for the perceived importance of sustainability in their professional contexts, the binary logistic regression model also clearly indicated that both gender and academic affiliation are significantly associated with social sustainability in higher public universities in Ethiopia, which is also more consistent with [67–71]. The results of our study show that female participation in research universities is less than that of applied and comprehensive universities in Ethiopia. However, in comprehensive universities, the participation of female instructors is higher than that in applied and research universities. Compared to the state of the art, our current work offers more advantages in addressing several factors responsible for contributing to social sustainability in Ethiopian higher education. In addition, evidence is drawn from factors associated with social sustainability attained through inferential approaches, which will support policy briefs and effective decision-making. To the best of our knowledge, our work fills the scarcity of literature reviews on this topic in Ethiopia and adds to the body of knowledge on social sustainability.

5. Conclusions

Exploring the roles and contributions of instructors in public higher education institutions in social sustainability is crucial for advancing sustainable development through educated human resources globally. However, this sector encounters significant challenges that impede instructor engagement. To address this issue, this study aims to investigate the role and contributions of public higher education instructors to provide valuable insights for policymakers, decision-makers, and leaders to foster a stable and sustainable society through the guidance of educators for national development. This study addressed three primary objectives: assessing the understanding of higher education instructors regarding their roles and responsibilities, evaluating their level of involvement in these areas, and identifying the factors that influence their engagement. In addition to assessment, this research seeks to emphasize the key variables that impact instructors' participation in social sustainability initiatives at higher public institutions in Ethiopia to inform policy briefs and decision-making processes. The research took place from December 2023 to 15 May 2024, and utilized a structured questionnaire to survey 460 instructors selected through stratified random sampling. These instructors were recruited from comprehensive, applied, and general research universities. This study used scientific methods to determine the sample size. The analysis, which included descriptive and inferential statistics along with chi-square and binary logistic regression models, revealed a significant level of engagement in social sustainability contributions among the respondents, indicating that female instructors showed less involvement than their male counterparts. Moreover, PhD instructors demonstrate a higher level of engagement in social sustainability contributions than those with master's degrees. Specifically, this study found that instructors in research institutions are 3.4 times more likely to contribute to social sustainability research than those in comprehensive institutions. Similarly, teachers involved in applied research are 2.2 times more likely to contribute to social sustainability than those in the reference category of comprehensive in public higher education institutions. This pinpoints that instructors in research institutions are more likely to be involved in social contribution than instructors in applied research. Additionally, the results reveal that females are 0.6 times less likely to be involved in social sustainability research than their male counterparts, indicating that males are more engaged in this area within public higher education institutions in Ethiopia. Furthermore, instructors who believe it is probable that the results of research conducted at higher education institutions will be implemented to solve social problems are 4.9 times more likely to contribute to social sustainability research than those who are definite in their belief that such implementation will not occur. Furthermore, the results show a statistically significant association between the predictor variables, such as university category, gender, qualifications, work experience, and social sustainability, at the 5% significance level. Finally, the overall goodness of the fit was checked, and it was confirmed that the model fits the data well. A 97.6% joint impact of the predictor variables explains social sustainability, which means that potential independent variables are involved in the article. Based on the result of the study, the researchers recommended that the Ministry of Education in Ethiopia should design policies and strategies to increase the participation of female university staff through targeted training and incentives, addressing the gender disparity observed in higher education institutions. In addition, policy designers should prioritize creating opportunities and resources for instructors to be motivated in research related to social sustainability. We also recommend that the Ministry of Education in Ethiopia evaluate and improve guidelines to prioritize the advancement of educators in higher education and promote their involvement in research and research-based community service. Moreover, while quantitative research is a reliable method of investigation, it is not a comprehensive approach that can fully capture the complexity and depth of understanding required to comprehend the issue under investigation. Therefore, we will also extend this work to conduct qualitative research to fully understand the challenges that affect higher education instructors' contributions to social sustainability and identify factors that enhance their contributions.

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Abbreviations

The following abbreviations are used in this manuscript:

MDPI	Multidisciplinary Digital Publishing Institute
DOAJ	Directory of Open Access Journals
TLA	Three letter acronym
LD	Linear dichroism

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