

Special Issue Reprint

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# Learning for Sustainability

Challenges and Progress of Embedding  
Sustainability into Teaching and Learning and Beyond

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Edited by  
Kelum Gamage and Neil Gordon

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# **Learning for Sustainability: Challenges and Progress of Embedding Sustainability into Teaching and Learning and Beyond**



# **Learning for Sustainability: Challenges and Progress of Embedding Sustainability into Teaching and Learning and Beyond**

Guest Editors

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**Neil Gordon**



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# About the Editors

## Kelum Gamage

Prof. Kelum Gamage (B.Sc., Ph.D., C.Eng., PFHEA, FIET, FRSA, and SMIEEE) is a Full Professor at the James Watt School of Engineering, University of Glasgow, and a winner of the 2020/21 University of Glasgow Teaching Excellence Award. As a leading advocate for sustainability in education, he co-founded and co-leads the University of Glasgow Community of Practice for Sustainability in Learning and Teaching and leads the AdvanceHE network on the same theme.

Prof. Gamage is the Editor-in-Chief for STEM Education section of *Education Science* journal and the Lead Editor of The Wiley Handbook of Sustainability in Higher Education Learning and Teaching. Nationally and internationally, he contributes to academic quality as a QAA (UK) Advisory Group member and an IET accreditor.

Prof. Gamage is a Principal Fellow of the HEA; Chartered Engineer; Fellow of both IET and RSA; and also a senior member of the IEEE.

## Neil Gordon

Neil Gordon is a Professor of Computer Science whose research bridges mathematics and computer science, focusing on finite geometry, formal methods, and educational technology. He leads a research group exploring how technology enhances learning and has collaborated with AdvanceHE on teaching innovation in higher education. After earning a joint degree in Mathematics and Computer Science and completing a Ph.D. in Applied Mathematics, he worked on geometry, group theory, and differential equations in mathematical physics. Neil later served as an Educational Technology Advisor, supporting tech integration in mathematics education. Since 2000, he has been a lecturer, taking on roles including programme leader, admissions officer, and head of Computer Science (2016–2018). He has also led Foundation Year programmes, KTP projects, and contributed to university-wide academic panels and initiatives in digital assessment and external examiner support. Neil chairs the BCS Ethics Specialist Group and speaks widely on ethics, sustainability, and generative AI.



# Preface

The COVID-19 pandemic has significantly impacted the education sector, disrupting traditional teaching models and prompting a rapid shift to remote and hybrid learning. Amidst these challenges, the crisis has also opened up new possibilities for embedding sustainability into education. This reprint arises from this transformative period, offering an opportunity to rethink how sustainability is integrated into higher education.

Educators and institutions worldwide have shown resilience and innovation, using this disruption as a catalyst to reevaluate priorities and adopt more inclusive, digital, and environmentally conscious approaches. In doing so, they have demonstrated how education itself can model sustainable practices in times of crisis.

This reprint compiles original research, case studies, and critical reviews that examine diverse strategies for embedding sustainability into learning, teaching, and assessing. It captures the contributions of scholars, educators, policymakers, and practitioners who have embraced the opportunity to reinforce sustainability in their educational practices, even under adverse conditions.

As the world moves forward, the insights offered in this reprint aim to guide the education sector in playing a key role in addressing global challenges and advancing the United Nations Sustainable Development Goals. Readers are encouraged to engage critically with the content and contribute to shaping a more resilient and sustainable educational future.

**Kelum Gamage and Neil Gordon**

*Guest Editors*



## Article

# Embedding Sustainability in Learning and Teaching: Lessons Learned and Moving Forward—Approaches in STEM Higher Education Programmes

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**Abstract:** Embedding sustainability into pedagogical approaches is a key priority in higher education. Equipping students with knowledge, understanding, and skills, and developing the next generation of innovators and leaders, can potentially provide the change needed and create a real impact in the journey to a sustainable future. Advancement in Science, Technology, Engineering, and Mathematics (STEM), and corresponding industries can be seen as vital for the success of meeting a majority of the sustainable development goals, and hence the approaches taken to embed sustainability in learning and teaching in STEM higher education programmes can be considered significant in many ways. This paper is based on published literature over the last two decades and a semi-structured interview with 12 university academics from a developing country. Hence, the paper reviews approaches taken to embed sustainability in learning, teaching and assessments in STEM programmes. It also aims to investigate the actions taken by universities to integrate sustainability in STEM education and the remedies taken to minimise the impact of the pandemic on the effectiveness of the learning pedagogies used to integrate sustainability concepts.

**Keywords:** sustainability; learning and teaching; STEM education; higher education



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## 1. Introduction

The coexistence and balance between humans and nature have been greatly challenged by the consequences of rapid economic growth triggered by scientific and technological innovations. As a result, the concept of sustainability, along with sustainable development and sustainable development goals, has evoked great concern from scientists, environmentalists, world leaders, and many others. According to the available literature, awareness of sustainability-related issues began in the 70s and continued being the focus of conference themes and academic papers, and the slogan of many development plans and projects and environmental-related activities, in the decades that followed.

As the motivations behind sustainability are complex and diverse, it has been defined from many perspectives. In the general sense, sustainability is the ability to maintain a certain level of balanced and stable development without disturbing the harmony between the natural world and the man-made physical world. Literally, sustainability means a capacity to maintain some entity, outcome, or process over time [1]. According to Stoddart et al. (2011) [2], sustainability is the efficient and equitable distribution of resources intra-generationally and inter-generationally with the operation of socio-economic activities within the confines of a finite ecosystem. Similarly, UNESCO (2012) [3] views sustainability as a paradigm for thinking about a future in which environmental, social, and economic considerations are balanced in the pursuit of development and improved quality of life. Accordingly, it is obvious that the term sustainability has always been focussed on

establishing a healthy relationship between social, economic, and environmental concepts, and issues of the present and future. They have also concentrated on transforming the global society, environment, and economy to the state of sustainability together.

Coupled with sustainability, the concept of sustainable development (SD) has also become a buzzword in development discourse, and is now associated with different definitions, meanings, and interpretations [4]. Among them, the most cited definition is the one proposed by the Brundtland Commission report (1987): “Sustainable development is meeting the needs of the present without compromising the ability of future generations to meet their needs [5]”. As a whole, SD aims at achieving social and cultural progress which, coupled with environmental equilibrium and economic growth, is a core concept within global development policy and agenda. The academic literature represents the aforementioned elements related to sustainability as the three-pillar conception of sustainability or the ‘Triple Bottom Line’: social, economic, and environmental.

In making the connections between sustainability and SD, sustainability is often thought of as a long-term goal while sustainable development refers to the many processes and pathways to achieve it [3]. Since education enables the young to fulfil their capabilities, it is a crucial investment for SD [6], and Education for Sustainable Development (ESD) extends its scope to deal with the complex amalgamation of issues relevant to environment, society, and economy [7] while paving the way for a more sustainable and just society for all. It encourages global changes in knowledge, skills, values, and attitudes while empowering and equipping current and future generations to meet their needs. Extending the landscape for SD further, the UN declared the period 2005–2014 as the United Nations Decade of Education for Sustainable Development (DESD) in 2002, emphasising the critical role of education in achieving sustainable development [7]. Taking the process of attaining global sustainability another step forward, the UN declared 17 Sustainable Development Goals (SDGs) in 2012 and education was given a crucial part because it is essential for progress on all goals [8]. Particularly, Goal 4 focused on quality education that ensures inclusive and equitable quality education and promotes lifelong learning opportunities for all; it linked to almost all the SDGs in one way or another.

Young generations as well as adults spend large periods of their life on education (formal, non-formal, and informal settings). The role of educational institutions, regardless of the academic level, is crucial in meeting sustainable development goals as they host basic skill development, and promote values, behaviours, and lifestyles favourable to a sustainable future and society while developing future professionals as change agents, and facilitating the creation of spaces where ideas are expressed freely, paradigms are challenged, creativity is promoted, and new knowledge is acquired and generated [9]. According to the UN (2007), “Academic institutions have the potential to generate a wave of positive change [10], and in achieving SDGs, higher education institutions have played a responsible role by implementing and driving sustainable development initiatives within their institutions”. In this discussion of sustainable development, McGunagle and Zizka [11] noted that Science, Technology, Engineering, and Mathematics (STEM) higher education programmes currently offer theoretical knowledge and industry-related competencies that seek to prepare graduates to become leaders capable of meeting 21st-century demands. Pahnke et al. [8] also built up the connection between STEM and sustainability, and said that STEM disciplines are called upon to participate in the social process of searching, learning, and shaping solutions to global sustainability issues.

Supporting the same point, Dotson et al. [12] suggested that access to quality education in STEM is linked to reduced poverty, higher economic growth, and more resilient democracies; these disciplines play an essential role in addressing many of the SDGs.

Scholars, practitioners, and policymakers are counting on STEM education to lead towards global sustainability. In that process, higher educational institutions (HEI) have been recognised as centres of knowledge generation and skill development. They are also expected to make a concerted effort towards shifting the focus from mere learning to learning sustainably, which is known as lifelong learning. Moreover, HEIs play a significant

role in inculcating in students the “values and skills that contribute to social progress and the advancement of knowledge” [10]. Hence, universities require innovative sustainability pedagogical methods for preparing students to create a more sustainable world through rigorous analysis and innovative solutions [13]. Traditional methods of lecture and assessment over-simplify complex issues and trade-offs into right or wrong answers; asking students to regenerate pre-packaged information presented by their teachers [14] and emphasising an individual’s knowledge-based achievements will not produce positive results in terms of sustainability. Moreover, many research studies have shown that didactic, teacher-centred education results in reduced cognitive, behavioural, and socio-emotional outcomes. Therefore, educating for sustainability requires that students develop the skills to be change agents who grapple with real-world challenges through explorations that engage multiple ways of knowing and move beyond facts as the central form of knowledge [14]. With respect to higher education and STEM education, a critical pedagogy including problem- or project-based learning, cooperative or collaborative learning, experimental learning, inquiry-based learning, case studies, and research-based learning, have been suggested as the most appropriate approaches by scholars. Hence, this article focuses on finding answers for the following research questions:

1. What is the role of STEM higher education in sustainability?
2. What kind of pedagogical strategies are used in STEM higher education to promote sustainability?
3. How do university academics perceive the sustainability concept in education?
4. What approaches are used usually to promote sustainability through teaching, especially during the pandemic?

Further, by answering the above questions, it aims to achieve the following objectives in relation to sustainability, higher education, STEM education, and learning pedagogies:

- Review approaches taken to embed sustainability in learning, teaching, and assessments in STEM programmes.
- Identify university academics’ views on promoting sustainability concept through higher education.
- Investigate actions taken by universities to minimise the impact of the pandemic on the effectiveness of learning pedagogies used to integrate sustainability in STEM education.

The background literature mainly focuses on the most applicable academic research outcomes for the main topic of study under areas of STEM higher education. It discusses the academic literary evidence for the role of STEM education in sustainability, and what are the most significant STEM educational pedagogies promoting sustainability.

## 2. Role of STEM in Sustainability

In general, STEM education refers to the teaching and learning method that integrates the content and skills of science, technology, engineering, and mathematics while providing students with opportunities to become problem solvers, innovators, inventors, logical thinkers, and tech literates. Alternatively, students get a chance to apply knowledge within meaningful real-life related contexts because it supports independent thinking and responsible action. It also reinforces engagement with technological and societal changes while enabling students to become responsible individuals who adopt sustainable development in their locality and, by extension, the global context.

STEM education is the integration of four disciplines with two possibilities: input and output in education [15]. The passage of content knowledge and development of skills in those disciplines function as the input. Conversely, STEM is also connected to economic competitiveness in the global market, and is required to fill output requests such as guaranteeing and maintaining energy and productivity needs [16]. Furthermore, STEM has been identified for its potential to contribute to positive social change through sustainability, considering that sustainability issues are inherently interdisciplinary.

Smith and Watson [17] used the Australian context to agree with the common perception that, for future prosperity, a substantial proportion of the global workforce needs to be educated in STEM disciplines. Further, investing in STEM education is key to productivity growth and higher living standards for our community, and it has been identified as the driving force for economic growth. Accordingly, applicability of STEM is the way forward for elevating sustainability in the universal perception. Hamilton and Thomas [18] also recognised that sustainability and sustainability science are increasingly becoming an accepted part of the general lexicon of STEM disciplines. Confirming it further, Zizka [19] said that STEM-related subjects are integral to sustainable development and for solving global sustainability issues in a meaningful and knowledge-based way.

In contrast to many favourable views on the relationship between STEM and sustainability, Davis [20] argues that STEM's contribution to sustainable development is limited. According to this argument, integrated and holistic approaches, rather than narrow STEM approaches, offer the best opportunities for successful and widespread ESD. It emphasises the need for rethinking STEM education as sustainability is fundamentally a human problem, not a science-and-technology problem. Further, the author supports the argument with Holbrook's (2009) suggestion: "Education for SD has little to do with accumulating a body of scientific knowledge, and is far more aligned with the development of personal and social aptitudes leading to responsible citizenship (p. 44)".

However, a sustainable future depends on a workforce of professionals knowledgeable about creating practices, processes, and infrastructure to optimise resource management, and a community informed about the ethics and influence of human activity on the integrated environmental, economic, and social aspects of sustainability [21]. As proven by the academic literature, systematic STEM education is capable of producing individuals to fulfill workforce requirements, which ultimately contributes to sustainable development both locally and globally.

### 2.1. University Sector

It is a known fact that higher education institutions (HEIs) play a key role in fostering social transformations that are critical for facilitating the transition to a sustainable future. Shepherd [22] defines higher education for sustainable development as "an approach to education aimed at responding to societal expectations to address environmental, social, cultural and economic issues that threaten sustainability of life on Earth". Similarly, Leifler and Dahlin [23] also confirm that higher education is instrumental in fostering the skills needed for graduates to become change agents for sustainable development. As recognised by scholars and policymakers, to best achieve the aims of the global sustainability agenda through education, there needs to be changes in educational policies, curriculum, and practices regardless of the academic level. Franco [24] highlights this in several studies and confirms the importance of a major transformation in higher education that needs to occur across all disciplines and levels of study.

Transversely, STEM higher education has been perceived as the key to propelling a nation from (1) developing to developed, (2) a middle-income country to a high-income country, and (3) one with a semi-skilled workforce to that with a highly skilled workforce [25]. In that case, as Zizka [19] suggests, for addressing sustainability in STEM education, HEIs must change the way students are taught to promote and provoke a more sustainable mindset. HE institutions need to teach sustainability, live it, and believe in it. Admittedly, lasting culture change requires commitment from the top. In line with expected advancements in the 21st century, there is global awareness for a shift in HE for sustainable development. That has been intensified with the start of the UNESCO Decade of Education for Sustainable Development (2005–2014), and universities have taken several approaches to rethink and amend their academic activities leading to sustainability. Weiss et al. [26] also noted the efforts of the UN to advance the implementation of ESD in HEIs in accordance with the strong impetus, support, and policy frameworks that have

been put forth by the UN decade for ESD (2005–2014) as well as the subsequent (2015–2019) Global Action Programme (GPA) and, most recently, the SDGs.

## 2.2. Industrial Sector

Financial instability and economic inequity, threats to food safety and increased health risks, climate change, biodiversity loss, decline in consumable water resources, and depletion of fossil fuels and energy sources are some of the interrelated issues that the world is facing today. Dotson et al. [12] supposed that access to quality education in STEM is linked to reduced poverty, economic growth, and more resilient democracies. In support of that, as mentioned in the literature, STEM competencies greatly impact each person's ability to contribute to economic success nationally and globally. As indicated through many research studies, STEM graduates come with strong soft skills (enterprise skills) and are much more employable [11]. Additionally, STEM has been recognised as the biggest asset to driving innovation and creativity. Moreover, a technology- and knowledge-driven economy needs workers trained in science, technology, engineering, and mathematics [27]. Hence it is long believed that STEM disciplines play an essential role in addressing many of the global issues related to the industrial sector.

Rapid technological advancement is a major driver of economic growth today, and the reason for improved living standards across the globe. Digital technologies radically transform the structure of every organisation reshaping the roles of professions. This has immensely influenced the field of education, including teaching and learning. There are indications of a fourth industrial revolution that is to come hand in hand with the development of digital technologies. Consequently, the future requires workers to think creatively, work collaboratively, deepen their emotional IQ, and integrate technology into everything they do [27]. STEM education has the potential to produce a workforce with a global mindset, critical thinking, problem-solving, and collaboration skill, which are highly required for sustainable development and central to innovation and a productive, adaptable workforce.

To prepare students for this technology-driven sustainability, the education system, especially higher education, should focus on developing skills required for sustainable development. Hence, HEFCE (2009) [28] states that the “greatest contribution HE can make to sustainable development is enable students to acquire the skills and knowledge that allow them to make a lasting difference”. HEFCE (2009:21) further suggests that in order to do this, the higher education sector must develop curricula and pedagogy that provide students with the required skills.

## 2.3. Curricular Changes and Integration of Sustainability

Over the last 20 years, scholars, activists, and others have noted that through the research they conduct, the engagement they experience with the broader community, and the operations they oversee, colleges and universities can serve as test sites and models for sustainable practices and societies [29]. Therefore, in the journey to sustainability, education should not restrict itself to just giving students information, but also provide them with an experience that brings opportunities to work collaboratively, appreciate multiple perspectives, be reflective, think critically and creatively, and act constructively [30]. According to AASHE [29], the existing curriculum in higher education has not been developed to examine how we can shape a sustainable world. Much of the curriculum has been developed to provide students with an increasingly narrow understanding of disciplines, professions, and jobs, and is focused on specific knowledge and skills employed in a given area. Consequently, to promote the change needed in society, HEIs themselves will need to change even quicker than society as a whole through attitudes enabling the integration of sustainability, regulations, standards, and faculty goals [23]. Alternatively, sustainability issues are complex, and vary locally and globally at different degrees. To ensure a more sustainable future, higher education will have to provide college and university graduates with the skills, background, knowledge, and mental habits that prepare them to meet

challenges in the future [29]. As a result, education for sustainability has become part of mainstream higher education policy in many countries. It encompasses various aspects, including knowledge of environmental, economic, and other social issues of sustainability; nurturing of ethos and values; and the adoption of participatory teaching and learning methods. Significantly, in the UK, progress has been largely confined to curriculum content changes [31,32] relating to cognition and knowledge. Its authorities have failed to deliver on other ideas, understandings, values, behaviours, and skills that are widely recognised as important to prepare graduates for future challenges. Hence, the need for more profound learning experiences that can equip graduates to make “informed decisions in their home, community and working lives” is being stressed upon. It is obvious that HE providers need to identify appropriate content and forms of teaching–learning to achieve sustainability-focussed learning outcomes along with proper assessment that can enhance sustainability skills and literacy in graduates.

An interdisciplinary, holistic, values-driven, and locally relevant curriculum integrated with sustainability concepts is highly recommended in higher education. Integrating sustainability into college and university curricula is challenging, but studies have shown a variety of attempts in this regard. According to the report “Embedding Sustainable Development in the Curriculum”, sustainability concepts have been fully integrated into some university courses. In the process of integrating ESD in HEIs, Weiss [26] identified two levels: micro and macro. At the micro level, integration is performed through teaching and learning in courses, while at the macro level, it is carried out through programmes and curricula.

Curriculum change processes are complex and vary remarkably, from institute to institute, programme to programme, sometimes even from discipline to discipline. They may even change in terms of their breadth, depth, and influences [26]. In addition to that, cluster analysis results of the study have revealed two distinct implementation phases: ESD can be implemented from the bottom-up, from the top-down, or both, and the impetus can stem from manifold external or internal stakeholders. Other than that, six distinct implementation patterns—(1) collaborative paradigm change, (2) bottom-up, evolving institutional change, (3) top-down, mandated institutional change, (4) externally driven initiatives, (5) isolated initiatives, and (6) limited institutional change—have also examined in the same study.

Leifler and Dahlin [23] specifically focussed on the views of Mulder (2017) regarding the integration of sustainability in engineering curricula, and as they have stated, generally the integration process follows one of two approaches, namely:

- (1) Focussing on analytical approaches of the impacts of technology such as life-cycle assessments of products.
- (2) Trying to achieve a positive system transformation through management and innovation related to technology and social change.

Taylor [21] specifically focussed on the possibility of integrating mathematics with sustainability. According to Taylor, sustainability can be addressed at all levels of the mathematics curriculum. Quantitative reasoning skills (logic, mathematics, and statistics) are also at the core of understanding and interpreting many sustainability concepts, and are required for making sustainability-related decisions. Further, it is essential in so many academic disciplines—not just the sciences, engineering, and economics, but also in history, linguistics, art, and media studies. Therefore, there are ample opportunities for introducing sustainability examples in math courses, from algebra and geometry to calculus and statistics, and even in advanced graduate-level courses. And the writer confirms the argument further by saying that quantitative reasoning in mathematics and sustainability have emerged as two similar, important, and mutually supportive themes that are critical for the individuals’ personal, professional, and public lives [21].

Parallel to that, Susilwati [33] established the relationship between science and sustainability. It was stressed that education leading to the sustainability of resources and the environment certainly needs to be integrated into science subjects. According to the views

of science, it reflects a holistic problem in real life. Natural science can be studied from several angles, namely as a body of knowledge, a way of thinking, a way of investigation, and its relation to technology and society.

Hamilton and Thomas [18] also propose a concise set of five learning objectives for sustainability education that can be included in almost any course while not sacrificing appropriate content.

- Teach in context: Include sustainability-oriented content and introduce “global realities”.
- Include real-life place-based examples.
- Emphasise “designing the future”. Teach the tools of complexity, systems thinking, and design thinking.
- Explicitly recognise the ethical and affective (moods, feelings, attitudes, etc.) aspects of the issues raised.
- Teach specific skills that empower students to become catalysts and leaders of change.

As they said, integrating sustainability education is possible if it can be incorporated into what is already being taught. However, there is no universal consensus on what specific sustainability-related competencies should be included in a curriculum or how it is to be performed, or when and where. To well establish sustainable education in the curriculum, it would require a remarkable modification in the way subjects are taught and learnt. To that end, more flexible pedagogical approaches combined with practical and applied learning opportunities are essential.

### 3. Learning Pedagogies in Embedding Sustainability in STEM

Broadly, pedagogy is referred to the whole learning process, which includes the learning environment, the learning community or the teacher and the students, and the assessment or reflection on the teaching–learning process. Westbrook et al. [34] viewed pedagogy itself as a contested term. According to Bernstein’s [35] definition, pedagogy is “a sustained process whereby somebody(s) acquires new forms or develops existing forms of conduct, knowledge, practice, and criteria from somebody(s) or something deemed to be an appropriate provider and evaluator”. In particular, it can be defined as the relationship between theories and practices used for educating somebody regardless of the academic level. Hence, for both school and university education, novel and innovative pedagogical methods are required to enable students to participate successfully in the sustainability process.

Sustainability issues affect personal, professional and social life. To build competence in sustainability and promote sustainable change, Redman [14] acknowledged the importance of integrating three critically significant elements: educational pedagogy, behavioural change, and sustainability competencies. Hence, pedagogical approaches are given a pivotal place in sustainability-focused education. This has resulted in a variety of creative and critical pedagogies. Redman [14] focused on a study performed on the effect of pedagogical approaches on sustainability courses, and found that multi-methodological, experiential, and active learning approaches improved students’ system thinking skills and provided a cognitive understanding of sustainability. Redman [14] advocates three interconnected pedagogical methods—real-world learning, critical problem-solving, and experiential learning—considering their significance to cognitive understanding and skill-building for sustainability. Moreover, Leifler and Dahlin [23] make references to several studies, stating that in both research and teaching, successful sustainability initiatives are characterised by strong inter-disciplinary activities, even ones transgressing disciplinary boundaries to reach solutions out of reach of any one discipline. Continuing the conversation on pedagogy for sustainable education, Sprain and Timpson [13] refer to several studies and state: “We realise that there are other approaches to teaching sustainability, including interdisciplinary student projects, field experiences, team-teaching with scholars from different disciplines, and games”. Hence, to build up a positive vision of the sustainable world that aims to create together, it is crucial to promote creativity, the ability to come up with innovative

solutions, responsibility, respect for the work at hand and other participants, and many other competencies through education. Teaching–learning processes containing creative and critical pedagogies can be assumed as the vehicles to reach the expected destinations. Specifically, teaching and learning methods for implementing STEM education as part of an interdisciplinary curriculum vary widely. They include project-based learning, problem-based learning, inquiry-based learning, and technology-based learning, each of which can be used differently depending on the classroom situation [36]. The pedagogies used and cited in empirical research studies related to STEM higher education and sustainability are discussed below.

Case studies have been identified as a productive pedagogical approach to teaching for and about sustainability by scholars. Sprain and Timpso [13] suggest that this pedagogical tool has interdisciplinary and even trans-disciplinary applications, and appears well suited to imply sustainability-directed STEM higher education. Furthermore, as a part of sustainability pedagogy, the case study approach can be used across disciplines (ecology, sociology, education, agricultural sciences, business, communication, etc.) at multiple levels, including in courses that are not explicitly about sustainability, environmental concerns, or even science. Schoolman et al. [37] also confirmed the appropriateness of the case study approach and said that they can be used in cross-listed or interdisciplinary courses that focus on the intersection of multiple disciplines, including courses on sustainability science, which is often envisioned as an interdisciplinary field.

Apart from that, Sprain and Timpson [13] highlight Seager et al.’s (2011) argument that case-based approaches are particularly well suited to teaching about sustainability and building capacity to address the challenge of tackling wicked sustainability problems. Further, it is acceptable that case studies can be used to build the capacities (systems thinking, anticipatory, normative, strategic, and interpersonal competencies) necessary to address problems of sustainability even in classes not explicitly focused on sustainability. More broadly, case-based approaches can be used as an educational tool to help students explore contemporary sustainability challenges.

### *3.1. Inquiry-Based, Problem-Based, and Project-Based Learning*

Within the concept of STEM Education, inquiry, project and problem-based learning are used to scientifically inquire about natural phenomena or problems or to introduce new concepts to the student during the teaching–learning process. Most specifically, these approaches address children’s inquisitiveness and thirst for exploration, their desire to get to the bottom of things and ask questions, while encouraging them to find answers for current issues with understanding. Common inquiry/problem/project-based STEM Education is built on constructivist theories of learning, and has long been applied in STEM, giving opportunities to explore ‘hands on’, experiment, ask questions, and develop responses based on reasoning. In addition to solving problems, students build a proper understanding of the phenomena of the natural world (‘minds on’) through in-depth study issues just as scientists do.

Martín-Garin et al. [38] recognised problem-based learning (PBL) as the most highly developed methodology in the university environment, where students work independently to explore a problem. In addition, Redman [14] says that problem-based learning centres on a complex problem that does not have a single correct solution. The critical thinking and problem-solving process should be student-led, experiential, and collaborative in order to emphasise that there is more than one correct point of view when exploring problems. The ultimate objective in PBL is not to solve the problem but to discuss how to solve the problem [38]. Considering the advantages of PBL, scholars have focussed on these approaches as effective teaching approaches to address the student community.

### *3.2. Real-World Learning*

Redman [14] emphasised the applicability of real-world learning in the pedagogy for sustainability and mentioned, referring to several empirical studies, that “real-world explo-

rations incorporate authentic investigations with complex goals and provide opportunities for problem-solving while involving students' beliefs and values". In contrast, Brundiens et al. [39] highlighted real-world learning opportunities that help students increase their understanding of sustainability problems (knowledge), and complement their methodological competence in applying problem-solving approaches (strategic competence cluster). They also allow students to gain hands-on experience in how to link knowledge to action for sustainability (practical competence cluster). Students learn to develop sustainability strategies and programmes in the actual context of existing processes, politics, or tradition. Moreover, real-world learning opportunities allow students to recognise and engage in different forms of collaboration at different degrees of intensity (collaborative competence cluster). Similarly, by providing assignments that focus on solving real sustainability issues, educators can engage students and help institutions turn towards more sustainable behavioural and policy norms. It also enables students to apply theory to practice, and builds interpersonal skills for engagement with stakeholders, both of which are critical for sustainability (Redman, 2019).

On the ground of all above, Brundiens et al. [39] suggested that through real-world learning experiences, students can apply their classroom learning to study the sustainability issue and engage with people in the community. Four methods for providing real-world learning experiences to students are: (1) bringing the real world into classrooms, (2) visiting the real world, (3) simulating the real world, and (4) engaging with the real world. Project- and problem-based learning, service learning, and internships expose students to corresponding real-world settings in communities, businesses, and governments, and have a common focus on real-world problems. Brundiens et al. [39] suggested these as effective in providing sustainability education since they seem to be a suitable way for students to develop key competencies in sustainability.

In addition to the above-mentioned approaches, Dotson et al. [12] termed co-learning framework and peer-led learning as two ways that ignite the aim to improve sustainability and scalability of STEM coursework in communities where this type of education is absent. Co-learning, also known as critical pedagogy, or experimental, cooperative, and/or collaborative learning, is a form of active, dynamic learning where students and teachers create a collaborative learning environment, in contrast with traditional passive teaching formats. Improved critical thinking, enhanced communication skills, improved socio-cultural awareness for both teachers and students, and a significant boost in student performance have been identified as the benefits of this approach.

In addition, Petrun Sayers et al. [40] prioritised cognitive maps as a STEM-based sustainability education evaluation tool. Importantly, cognitive mapping plays an interesting role in the field of sustainability because the tool can effectively capture the field's interdisciplinary nature. It has also proven to be a tool for building and examining understanding of additional STEM and sustainability concepts. Mathematical modelling has also been tested as an effective pedagogical strategy in STEM projects to enrich students' competencies regarding sustainability in higher education [36]. Mathematical modelling describes a set of comprehensive processes used to transform real-life problem situations into mathematical models, draw mathematical conclusions, and then apply those conclusions back to the real world.

Dawe et al. [41] categorised pedagogical applications commonly used for teaching sustainability in Embedding ESD into Higher Education: Final Report for the Higher Education Academy, teaching methods employed in the delivery of sustainability.

- Conventional methods: lectures, seminars and tutorials
- The personal: role models
- Re-connecting to reality: real-life and real-time interpretation, field trips, environmental audits, the use of role-playing, a year abroad; and development of case-studies
- Holistic thinking

As a whole, the above discussed pedagogical approaches appear to be student-centred and capable of offering a holistic education catering to the needs of education for sustainable development.

#### 4. Materials and Methods

This research article has followed a qualitative approach that is mainly based on two types of data, taken from systematic document analysis and interviews with university academics. Literature for the analysis of the documents was exclusively retrieved from online databases. Predetermined selection criteria were applied during the database search in order to keep the number of articles reasonable, and to ensure the quality of the sources. The search was restricted to peer-reviewed journal articles, conference papers, and reports in full text. There were no restrictions on the year of publication or the geographical regions considered, and the selection of documents followed text titles, abstracts, and whole texts that appeared in databases of Google Scholar, J-store, Tandfonline, Elsevier, and recognised institutional websites (e.g., UNESCO).

In the selection process, both empirical and theoretical studies were included regardless of the research method followed. The comprehensive search resources were completed based on a wide range of key terms and phrases, including “Sustainability and Education for Sustainable development, STEM higher education, Learning pedagogies for sustainability learning, and STEM-related learning pedagogies”. Similar terms that are often used interchangeably in the literature were also used. As the search action resulted in a limited number of appropriate and accessible sources, the reference section of the recovered texts were studied for more relevant texts. As a whole, the original samples came up to 235 documents and their abstracts, and the contents were examined in detail. This led to the removal of duplicates and articles with directly unrelated content, and the original samples were reduced to 57 articles. Finally, the content of the selected resources was studied and analysed.

As the other source of data, discussions with 12 select university academics from the Science, Engineering, Mathematics, Agriculture, Information and Communication fields were conducted. In the selection, their preferences to participate in the discussion were considered. The interview was a semi-structured interview, and the interviewer used a set of predetermined questions related to the cause of the study. The respondents were allowed to express their views on the implementation of education for sustainable development, pedagogical approaches, and how current educational practices focussing on education for sustainability have been impacted by the pandemic situation. Interview transcripts were made, and responses were analysed narratively and reported according to the question order in the interview schedule. Then the required data were organised into two main sections to answer the research questions.

#### 5. Results and Discussion

The following section focusses on examining learning pedagogies practised in the process of embedding sustainability in STEM, as reported in the research literature. Further, it prominently answers the second research question. The third and fourth questions are answered through interview data, i.e., the experiences of university academics in delivering sustainability concepts during the teaching–learning process.

##### 5.1. Analysis of Learning Pedagogies in Embedding Sustainability in STEM

STEM instructions transform the conventional teacher-centred teaching–learning into active student-centred learning with the use of the following pedagogical instructions: inquiry, PBL, case studies, argumentation and reasoning, digital learning, computer programming and robotics, and cooperative learning, among others. Many of the research study results have validated the effectiveness of pedagogical strategies in STEM education promoting ESD [36].

There has been widespread discussion on innovative sustainability pedagogies. For example, studies by Küçüksayrac and Kırca [42] and Hansen et al. [43] have confirmed that sustainability is closely connected with contextualised problem-based STEM projects and, as such, is best to integrate sustainability concepts into the STEM teaching–learning process. Furthermore, Martín-Garin et al. [38] reported the pedagogical approaches developed and applied by a multidisciplinary team in the Civil Engineering and Technical Architecture degree programme during the academic years 2013–2014, in a university from Spain. According to that PBL or RBL (research-based learning), life cycle assessment (LCA) and computational thinking (CT) approaches have been used with an aim to acquire a sustainable approach to work “soft skills” competencies into sustainability. As it reported, implementing PBL resulted in higher achievements in exams of physical and mechanical properties (Engineering), together with improvements in teamwork and collaboration as well as increased awareness of climate change. As a whole, they all stress the importance of acquiring sustainability skills through study modules as part of students’ professional qualification profiles.

Moreover, Dobson and Tomkinson [44] stated that using inter-disciplinary problem-based approaches to embedding SD in the curriculum is not only practicable but also desirable. However, the approach to the design of problem scenarios has to be adjusted to the nature of the “wickedness” of sustainability issues, and be appropriate to the student cohort and institution.

The study of Suh and Han [36], which used mathematical modelling to bridge STEM education with ESD, revealed that it is effective in inducing positive change in students’ perceptions about the use of STEM for predicting future societies and sustainable development, and making responsible decisions that promote harmony among the environmental, economic, and social domains. Further, Peter and Reid [45] argued that broader and more holistic conceptions of mathematics allow room for integration with the broader conceptions of sustainability, and mathematical modelling facilitates that requirement. Cognitive mapping is a proven, useful tool for building and examining an understanding of additional STEM and sustainability concepts. Cognitive mapping can assist instructors in tracking student progress with sustainability concepts and test the effectiveness of curricular interventions. The method suggests how students conceptualise and organise knowledge in an open-end format, offering an alternative to multiple-choice or sheer memorisation techniques, and moving towards a method that allows students to integrate diverse higher-order constructs to develop metaphorical thinking [40].

Case-based teaching has long been used as an effective pedagogical practice in many disciplines. Hardin et al. [46] and Wei et al. [47] referred to the Michigan Sustainability Case (MSC) initiative as an innovative attempt to equip the next generation of scientists and professionals with the competencies necessary to understand, analyse, and solve wicked sustainability challenges. Similarly, Davis [48] also highlights the importance of introducing and effectively integrating case studies on sustainable development into traditional engineering disciplines. Based on his study, he concluded that case studies allow students to visualise how sustainable development can be applied to all engineering decisions, and also give them the capacity to understand the social, environmental, and economic considerations associated with all projects, as well as in the application of their knowledge and skills to make informed engineering decisions. Standing on the findings of a study to design a MetaMAP (an interactive graphic tool for collaborating to understand social-ecological systems and design well-integrated solutions), Maher et al. [49] discussed the benefits of case study-design approach to achieve sustainable development goals.

Wei et al. [47] analysed the outcomes of a case study based on environmental education and said that with regard to case studies, some evidence exists that their use promotes knowledge gains, critical thinking, and problem-solving skills. Additional evidence indicates that teaching through cases and examples that provide “real-world” relevance (i.e., “socio-scientific issues”) increases students’ interest and engagement in learning, and

promotes the development of higher-order thinking. The case study method fits the lessons for teaching sustainability and addressing problems inherent in sustainable development.

Sadowski et al. [50] discussed the effect of the “game-theoretic, experiential pedagogy”, which moves the learning experience from passive to active, apathetic to emotionally invested, narratively closed to experimentally open, and predictable to surprising. Basically, it focusses on ethical skill development in science and engineering students, and researchers have seen positive results in relation to the content knowledge and sustainability ethics of students.

Most higher education institutions tend to integrate e-learning within their pedagogical provisions, and it has become crucial as a result of the pandemic. It focusses on enhancing teaching–learning, student assessment, and improving students’ satisfaction and outcome. Even before the pandemic situation, e-learning had gained considerable attention. Altomonte et al. [51] aimed to explore the opportunities offered by interactive and situated learning (e-learning and m-learning) in support of education for sustainability in disciplines of the built environment. The findings have added empirical evidence to the view that information and communication technology-enhanced pedagogies can substantially contribute to the agenda of sustainability in higher education, primarily due to their affordance of interactive communication and contextualisation of knowledge, while guaranteeing flexible time and pace of learning.

As a whole, it is evident that PBL and case studies have been identified as the leading pedagogical approaches to developing sustainability skills. Game-based learning approaches and cognitive mapping are similarly recognised as influential. There is increased popularity for e-learning due to the pandemic situation too. Hence, the following sub-topic will concentrate on discussing the experiences of academics in a developing country, revealing the current practices related to that context.

## 5.2. *Views of University Academics of a Developing Country*

### 5.2.1. General Views on “Sustainability” Concepts as University Academics

The university academics who participated in the study generally view sustainability as a very important and essential concept for everyone everywhere, especially in the future, due to the scarcity of resources. They also perceive sustainability as a broad and progressive concept that is relevant, and can be applied at any level (e.g., national, regional, organisational, and personal). They recommend that sustainability be adopted in every possible field since it is one of the major areas that need to be focussed on for ensuring the continued existence of the world. Hence, considering its ability to uphold the individual, the community, and the whole world, sustainability must be implemented rather than used as an object of mere rhetoric.

Sustainability is required to create a conducive living environment while maintaining the good of all and carrying out daily activities. It is the process of meeting one’s own needs without compromising the ability of future generations to meet their needs. Sustainability is a solution/approach/practice that performs well in the social, economic and environmental dimensions. It is a concept aimed at ensuring that things exist without interrupting other systems around them, and humans grow, develop, and gain resources without compromising the ability of future generations to do the same.

In response to the question “What are your general views on sustainability?”, some highlighted the relationship between education and sustainability. According to them, “Education, research, and innovation are essential for sustainable development. University researchers, teachers, and students work in partnership with citizens and the private and the public sector, co-creating knowledge that can produce solutions”. Another point that emerged from the responses was the concept of a sustainable university. “A sustainable university is an educational institution that educates global citizens on sustainable development, offers relevant insights on urgent societal challenges, reduces the environmental and social footprints of its campus operations, empowers students and staff to act, and makes sustainability a central priority”, they said. They also highlighted the importance of

university education, and proposed that university education graph all modern techniques and latest updates (knowledge) that need to be transferred to students. To support that, university curriculum should provide more opportunities for students to become familiar with sustainability concepts. University academics hold a similar perception on sustainability to that defined in the academic literature. Additionally, they agree that sustainability is becoming more and more important in all aspects of life, and university academics are responsible for making a key contribution to achieving the goals.

### 5.2.2. Views on Education for Sustainable Development

Education on sustainable development has been perceived as a necessity and timely topic that should be addressed at every level of education, whether school, university, or other educational settings. Especially for higher education institutions, it is a very important topic aligned with the objective of achieving the UN's SDGs. Henceforth, all forms of education should have subject components on overall sustainability as well as those specific to the study area/field of speciality. In the same way, ESD has been suggested as mandatory for education, and should be associated with all disciplines.

ESD has been identified as “a process that promotes the development of knowledge, skills, understanding, values, and the actions required for creating a sustainable world that ensures environmental protection and conservation, promotes social equity, and encourages economic sustainability”. A similar explanation also emerged from the discussion: “Education on sustainable development empowers learners with knowledge, skills, values, and the attitude to make informed decisions and take responsible actions for environmental integrity, economic viability, and a just society”. It is in contrast with the idea of those who see ESD as a concept that thinks only about environmental protection. ESD has been recognised as highly needed for every student and academic today and in the future. There is emphasis on the need for awareness after university study.

### 5.2.3. Consideration Is Given for “Education for Sustainable Development” within the Academic Activities and Pedagogies in Practice

According to the responses of the academics, a majority consider education for sustainable development as essential, and they provide space for it in their teaching. However, some were not sure about making room for ESD experiences, and provided “maybe” as the answer. Remarkably, one even answered with a “no”, contending that within the teaching and learning process there is no chance for the concept of ESD. This indicates the unawareness of the importance of ESD initiatives among academics, and further, portrays their uncertainty and lack of readiness in incorporating sustainability criteria into their professional practices. Moreover, it sheds a critical light on the consequences that may be expected in the future due to the lack of preparedness of university teachers for change.

On integrating sustainability concepts in university courses, it was revealed that much consideration was given to the subject particularly in engineering. Three academics came out with their personal involvement in integrating sustainability.

- Academic 1: “I introduced a technical elective on Sustainable Manufacturing in 2013, and it has now become a core course in the Manufacturing and Industrial Engineering Bachelors’ programme”.
- Academic 2: “I teach the following concepts related to sustainability: resource and energy sustainability, environmental sustainability, product life cycle sustainability, sustainable consumption and production”.
- Academic 3: “I have given prominence to integrating USDGs in all my teaching and research activities for several years now”.

The above statements reflect that academics involve themselves in sustainability initiatives and sometimes work in an uncoordinated manner or in isolation. Hence, it is crucial to create collaborative networks between academics and connect them with one another to strengthen involvement in ESD [52]. Further, it is evident that although substantial space is given for sustainability concepts, it is still limited. Hence, more improvements are

necessary, considering that it is a compulsory requirement. The academics specified that it is theoretically adequate but not practically so, and further highlighted the need to update every syllabus.

Basically, different kinds of models for teaching and learning are required to meet the needs of the students, and it depends on many factors. Additionally, variations in methods help students employ and develop different learning processes, making them grow as learners, and enhancing their skills and capacities to learn and think [16]. During the discussion, project/problem-based learning and case studies were suggested by a majority of the academics as the most appropriate pedagogical approach to deliver sustainability concepts. The literature suggests that case studies are a productive approach to teaching about sustainability and teaching for sustainability. Similarly, role play, discussions and debates, and field visits were also recommended as effective approaches by many of the academics. Online simulations and business games were also favoured. In addition, sustainability scholars have pointed to experiential learning strategies as ways to empower, engage, and motivate students while also disposing of the typical compartmentalization between action and education [14].

Although the lecture method is considered traditional and still applies in all types of education, many prefer it for use in teaching sustainability. Seminars, tutorials, and mind mapping were the least recommended approaches. Remarkably, one answered with a “no idea”, and it acknowledges the capacity of academics to develop students’ sustainability practices while highlighting the importance of timely professional training. As Seatter and Ceulemnas [9] argued, the use of a particular methodology is highly dependent on the target (pedagogical and educational goals) and situational specifics (regarding students, teachers, and the learning environment) in which they will be used. Hence, if the academics are not aware of the applicable methodologies to be used, or if they stick to the same pedagogy for every lesson or activity during the teaching–learning process, it would hinder the achievement of situation-specific educational goals. Universities in the 21st century are obliged to train the younger generation to face the challenges to come, and that demands the application of new educational practices and models in the teaching–learning process to make it more productive. Hence, there is a rising need for updating knowledge and professional practices. The possible reasons that academics found for not including SDGs in their activity may have been the consequences of lack of training, opportunities, materials, time, and unawareness of the current trends in the field. For this reason, it is essential to train them, and motivate them to change their practices and attitude. Adding value to activities related to the integration of SDGs in the university curriculum is also needed.

#### 5.2.4. Believes in Embedding SD into Subjects and Teaching as a Separate Subject

The very nature of sustainable development is complex, and multidisciplinary at many levels [53]. Almost all the academics who participated in the conversation suggested that embedding it into subjects is the best way to improve the efficiency of passing sustainability concepts to students at the university level. At this point, they proposed that embedding the concepts is more efficient if it is performed in combination with problem/project-based learning, research case studies, fieldwork assignments, and assessments on the subjects. Contrastingly, a few think that teaching it as a separate subject would be more effective. However, for a better sustainability learning experience, different subjects and disciplines need to be integrated and university classes need to be connected to real-world problems and actors. This requires applying the principles of interdisciplinary, trans-disciplinary, and self-regulated learning [9].

#### 5.2.5. Contribution of Academic and Non-Academic Activities at the University to Enhance Knowledge and Skills Needed for SD

For the question on the status of current academic activities to enhance knowledge and skills needed for sustainability development, it was revealed that the space given for sustainability concepts was either less, moderate, or average but not adequate. Hence there

is room for improvement. Furthermore, as shown at the moment, there are some initiatives but they are still isolated and need to be connected with the mainstream across faculties, departments, and even degree program level at universities. Nevertheless, they are trying their best to contribute the knowledge and skills enhancement needed for sustainability development through most academic activities.

We then tried to find out more about the opportunities provided by universities to students to contribute their knowledge and skills for becoming a part of the journey to sustainability. It was revealed that students benefit from volunteer projects (projects as general electives and assignments of core modules), social activities, clubs, industrial training, internship programmes, scientific research opportunities, field visits, competitions based on sustainable concepts, seminars, lectures, and other university/faculty-level sustainability initiatives.

The academics said: “It’s not something to teach. But it’s something to feel. We should make them feel and get involved in it”. There are many opportunities in the industry and civil organizations to learn and practice sustainability too. However, two participants stated that they are not aware of such opportunities for the students, and another said it is not applicable. It seems that there is room for improvement in their way of thinking and practices as academics in order to create a new educational paradigm ESD.

Integrating sustainability concepts in higher education has been studied in many contexts. Providing empirical evidence for its effectiveness, Qu et al. [54] observed significant changes in the knowledge and attitudes of students after integrating engineering curriculum with sustainability concepts. And that would be equally applicable for other disciplines too. On the other hand, teaching is not the only area of activity where sustainable development is becoming increasingly important. Research at many universities is playing an increasingly important role, both in terms of academics and financial support [48]. On the whole, higher education for sustainability should potentially support and facilitate transformative learning that demands asking critical questions, continually search for new sources and ideas, and encourage creativity and organizational learning [9]. Vice versa, the very nature of sustainability as a contested, multilayered and multifaceted subject provides rich opportunities for critical thinking and transformative learning [53].

#### 5.2.6. Suggestions to Improve Academic Activities/Courses Suite to Achieve Sustainability Locally and Globally

Referring to several studies, Qu et al. [54] specified that embedding sustainability into the curriculum does not merely mean an add-on of new content to enhance the existing knowledge base of sustainability. Rather, it is a fundamental element. Consequently, it is important to automatically initiate a transformational routine, where there is expectation that knowledge will be facilitated toward developing sustainable behaviours.

When considering the world scenario, various attempts have been made to uplift the concept of ESD in university education. During the conversations, several suggestions were made by the academics to improve the academic activities/courses suite to achieve sustainability locally and globally. Basically, partnerships at all levels are considered prominent while integrating the sustainability concept as the basis of every discipline related to development to enhance the credibility of the subject. Along with these, creating opportunities to update and increase the awareness of academics and students in other countries is also seen as a timely requirement.

Besides focusing on curriculum and pedagogical practices, they agreed that curriculum amendments are important because students should be provided with the experience within the discipline. Introduction of practically oriented disciplines; adding the sustainability concept to teaching and practical activities; conducting specialised workshops; implementing modern teaching concepts (PBL, case studies); encouraging lifelong learning; linking sustainability-related current world issues, challenges, and achievements with academic work; focusing on global trends for sustainability during the teaching–learning process; and providing regular insights on sustainable development were the most com-

mon suggestions made to improve education on sustainability. Other than that, they recommended giving more weight to topics such as “resource and energy sustainability, sustainable consumption and production, environmental sustainability, social sustainability, economic sustainability, and product life cycle sustainability”. All in all, it was concluded that integrated and holistic discussion is needed in this case.

According to UNESCO [19], the goal of higher education is to support students in developing the capacity to recognise and understand the complexity of sustainability issues, and think critically about assumptions, biases, beliefs, and attitudes while actively participating in their resolutions. To achieve education in sustainable development, it is also necessary to provide individuals/students more than just the knowledge and skills needed to recognise sustainable development, but the capacity to develop sustainable development practices in their own world too [3].

#### 5.2.7. The Impact of Online/Hybrid Teaching

Due to the prevailing global pandemic, the mode of education has been shifted to digital platforms. As Gonzalez-Gomez and Jeong [55] mentioned, e-learning and online learning are now considered as teaching–learning processes based on a proper educational model, which allows flexible and pertinent learner-centred education due to ICTs in sustainability education. Within that environment, embedding sustainability experiences in learning and teaching practices is really challenging. Hence the impact of online/hybrid learning was discussed, and it resulted in mixed views without being biased towards either end.

Basically, online mode has been taken up as a way to continue education at the global level, and accelerate the learning and teaching practice significantly through the past two years. It has had a mixed impact, affecting students in both negative and positive ways. However, the impact of blended learning on SD is very high, and it reinforces the process that emerged in the discussions. Furthermore, hybrid teaching has been accepted as the most efficient and effective alternative, although it has changed the landscape of the journey to embedding sustainability in learning and teaching practices. Another argument put forward was the impact of resource availability to conduct hybrid teaching–learning, and the need for improvement to achieve productive education. So there is a greater requirement to enhance aspects such as resources, and effective ways to convey SD ideas to the audience.

On the other hand, it was stated that “online teaching provides fewer opportunities to deliver and practice SD concepts due to limited opportunities to communicate and conduct fieldwork”. Hence, it is suggested that effectiveness has decreased as online platforms are good for discussions but not practice. Remarkably, some contradicted both the positive and negative observations mentioned above, arguing that impact is based on the teacher and not on the mode of teaching. Further, it was reasoned out that “if the course content is delivered and there is emphasis on the value of the subject, it does not matter how the lectures are delivered”.

“No idea” was also received as a response, and it once again brought into question the up-to-dateness of the academic. It also brought into question the capabilities and attitude of the academic as a responsible professional. The responsibility of the university is not merely to make students knowledgeable, but also to guide them into finding new knowledge and competencies, and making them aware of the changes and challenges. To facilitate this, university academics need to have a clear perception of the trends and changes in the contemporary world.

## 6. Conclusions

Science and technological advancements have raised the living standards of people enormously, and this, in turn, has resulted in many global issues. In such a scenario, transforming mere development into sustainable development became a matter of universal

concern. Simultaneously, education started being recognised as the means for building a future with balanced economical, ecological, and social sustainability.

Accordingly, it is important to develop learning environments that encourage students to acquire knowledge and skills while developing the right attitude. According to Mulder [56], sustainability demands a specific kind of learning. Some authors call for a deep change in society to achieve a sustainable society. “Sustainable development is not just a matter of acquiring some extra knowledge. Attitude is also important. Moreover, it is often necessary to change social structures”, they say.

In the way forward to sustainability, empowering present and future generations with STEM knowledge and skills is recognised as essential. Therefore, there is a requirement for high-quality STEM education through which students experience innovative pedagogical strategies, interactive learner-centred teaching, and learning environments, to meet the requirements of ESD. Traditional teacher-centred teaching and learning methods limit opportunities for experiential learning, critical thinking, reflective reasoning, and involvement in solving complex problems and growing into a responsible citizen. Hence, Pahnke et al. [8] proposed that STEM experience should promote inquiry-based learning and scientific thinking, and encourage interactive, learner-centred teaching that enables exploratory, action-oriented, reflective, and transformative learning. Notably, the need for learner-centred innovative approaches for sustainability-oriented higher education has emerged from the literature and from discussions with academics.

To achieve the goals of education for sustainability, it is obligatory to implement an appropriate pedagogy in the teaching–learning process. In the sense of pedagogy for sustainability, it is mainly problem/project-based learning, real-world or experiential learning, case studies, and e-learning that can develop outcomes in the form of changes in individual behaviour towards sustainability goals. They enhance the domains of knowledge, skills, and attitudes expected in ESD. However, when analysing pedagogical approaches and their suitability to teaching/learning SD, the traditional lecture method is still in practice. Seatter and Ceulemans [9] confirmed it further, highlighting that current sustainability teaching in higher education pedagogy lacks the sustenance to facilitate sustainability thinking and behaviour, and often is stymied by a transmissive and lecture-driven delivery. Hence, there is consensus about the need to move from the traditional way to an alternative one so as to allow students to achieve SD competencies in both cognitive (knowledge and understanding) and meta-cognitive (skills and abilities and attitudes) domains. However, all pedagogical methods will not be suitable for every subject, target group, and culture they are going to be implemented on. Therefore, the pedagogy needs to be selected suitably. Susilwati et al. [33] suggested a pedagogy for sustainable development that consisted of four components, which are (1) system thinking and understanding of interconnectedness, (2) long-term, foresighted reasoning, and strategizing, (3) stakeholder engagement and group collaboration, and (4) action orientation and change agent skills.

Attaining sustainability is a long-term process, and education is a pivotal factor in it. It also depends on the collective participation of all the individuals involved, especially teachers and students. Segalàs et al. [57] found that students perceived sustainability as mainly related to technology, and saw little relevance in social and attitudinal aspects. Seatter and Ceulemans [9] also saw that challenges to teaching sustainable development in higher education could mean that students—as future citizens—are left without insight, commitment, or any sense of their position with regard to meaningful beliefs and actions on sustainability. Hence, to achieve education for sustainability, the development of a proper curriculum that has the potential to enhance skills for sustainability is a necessity. Another important requirement for meaningful sustainability curriculum transformation is the involvement of academics. According to Zamora-Polo and Martín [52], academics are very important and relevant in the whole teaching–learning process because they organise the teaching activity, and programme the learning plan that students need to take to achieve success. Barth [16] pointed out that lack of training and different academic backgrounds may also become barriers. Other than that, lack of knowledge of SD and interdisciplinary

competence, lack of interest and understanding, and limitations placed on research and further studies are also in the line. On the other hand, as Zamora-Polo and Martín [52] stated, activities promoting sustainability have traditionally not been valued in teachers' curricula. In that case, motivating for attitudinal change, showing readiness to work across disciplinary boundaries, and providing the required facilities, besides training and funding, are required to overcome the issue. On the whole, individual and collective actions bring about the transformation in higher education, promoting learning for sustainable development. Therefore, teachers, education policymakers, and administrators should go for timely reforms in every context.

The establishment of education for sustainability is hindered by many major and minor factors, with geographical, political, and socio-economical inequalities at the forefront. Most significantly, with the pandemic, education has moved to virtual mode, specifically impacting developing countries due to their lack of resource availability, readiness, and other factors. Thus, more efforts are needed to reduce differences around the world. Additionally, there has been high recognition of science, technology and instrumental knowledge to the detriment of human development and related aspects such as ethics, values, and social knowledge. Transforming education is the biggest deciding factor for transforming societal systems, and as the means for meaningful development, the requirement for sustainability education needs to be addressed with the re-orientation of STEM education in combination with other areas such as sociology and humanities. On the whole, to create a more sustainable world, individuals need to equip themselves with the requisite knowledge, skills, values, and attitudes that will empower them to contribute to sustainable development, and that can be achieved only through the collaborative effort of all participants.

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## Article

# A Methodology to Introduce Sustainable Development Goals in Engineering Degrees by Means of Multidisciplinary Projects

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**Abstract:** The sustainable development goals (SDGs) reflect the relevance that sustainability is gaining in our societies. Including sustainability-related topics in university curricula requires the revision of the contents, teaching/learning strategies and assessment techniques. Although engineering degrees are starting to introduce them, it may become complex to design significant educational experiences. This partly comes from the fact that sustainability is a highly multidisciplinary issue but, currently, the knowledge is compartmentalised into subjects. In this challenging scenario, concrete activities are required for students to better internalise sustainability issues. This work aims to present a methodology that guides academic staff to materialise the design of sustainability-related multidisciplinary activities. Since the designers of new activities may benefit from knowledge of similar experiences, this article describes one implementation throughout eight subjects within the Bachelor's degree on Industrial Electronics and Automation Engineering at UPV/EHU. The analysis and optimisation of the thermal comfort and energy consumption in the Faculty building became the common thread to design an educational itinerary that covers several subjects along all academic years of the degree, making use of active methodologies. The problem is analysed for every subject from different perspectives. Two questionnaires, carried out before and after the activities, were used for analysing the perception of the students after the activities. Results proved that the multidisciplinary project raised awareness about the SDGs and allowed students to visualise how to apply the acquired skills in problems close to their experience. As a result, more students considered sustainability as a possible future professional activity.

**Keywords:** sustainable development goals (SDGs); active methodologies; multidisciplinary education; engineering education; indoor environmental quality (IEQ); thermal comfort; energy economy



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## 1. Introduction

The concepts of sustainable development and the sustainable development goals (SDGs) were defined at the United Nations Conference on Sustainable Development in Rio de Janeiro in 1992 [1] and were adopted in the 2030 Agenda for Sustainable Development at the United Nations General Assembly in 2015 [2]. Currently, an increasing number of educational institutions are incorporating sustainable development into their curricula in order to better prepare students for a changing world, which requires renewing these curricula [3,4]. Unfortunately, this is a complex task [5], since sustainability issues are

typically wicked problems, i.e., highly complex, ill-structured and domain-specific problems, which are difficult to approach [6]. Among other issues, sustainable development is inherently multidisciplinary and requires combining approaches from different disciplines, involving social, economic and scientific aspects to implement engineering solutions [7,8]. However, a systematic approach should be followed in order to coherently introduce the SDGs into educative programs. For example, in [9], six SDG transformations are introduced as modular building-blocks to achieve the SDGs. This approach creates groups of SDGs in order to organise their implementation.

Some works present guidelines and experiences that are aimed at guiding institutions to include sustainability in High Education Institutions (HEI) [10]. Other works [11] recommend focusing on the following lines of action: (1) interuniversity collaboration among entities, (2) multidisciplinary promotion, and (3) adequate selection of real-use cases that illustrate problems as well as possible solutions. Certain authors suggest that engineering students need specific training in transdisciplinary research and conflict resolution to avoid situations in which they collapse in frustration when dealing with real problems [12].

One common problem in engineering studies is that, although design is a fundamental part in engineering sciences, sometimes it may be excluded from the teaching curriculum. Hence, future engineers may lack creativity and have a narrow problem-solving focus, with too much emphasis on mastering mathematical equations [13]. In most cases, incorporating tangible and relevant challenges into the curriculum requires breaking away from the traditional teacher-centred approach, based on lectures and knowledge compartmentalisation into subjects. This trend follows the Barcelona Declaration, signed in 2004 [14], which stated that, nowadays, engineering education should be multidisciplinary, holistic and systems-oriented and it should foster critical thinking and participation. Hence, graduating students should acquire these competences during their studies since they will be required in the future professional practice.

In this context, active methodologies have proven to be effective to motivate students, achieving deeper learning and helping students to better retain knowledge [15–19]. Some works analyse the synergies between sustainability education and active methodologies, such as problem-based learning (PBL) [20,21], challenge-based learning (CBL) [22] or design-centric engineering [4]. According to these studies, active methodologies are particularly suitable for developing the concept of sustainability in educational programs. According to [23], in the case of the PBL methodology, the proposal of problems close to the students' interests produces better results since they benefit from their direct experience.

Consequently, university curricula should be adapted to raise student awareness on the concepts of sustainability and sustainable development. In addition, it is essential to introduce methodological changes aimed at making students more active in their learning processes. In this scenario, the following research questions arise:

**RQ1:** How to introduce the SDGs in the curricula of engineering degrees by means of concrete activities;

**RQ2:** How multidisciplinary experiences, which intertwine several subjects, should be designed to engage students;

**RQ3:** How to make students aware that the skills acquired during the degree may help them to design and develop sustainability-related projects in their future professional activity.

After carefully analysing the current situation towards sustainability in HEIs, this article proposes a methodology that guides professors and instructors to materialise the design of multidisciplinary activities aimed at introducing the SDGs in the curricula of engineering degrees. The presented approach requires that students face a multidisciplinary problem linked to the SDGs, which becomes the common thread to combine knowledge and skills acquired from different subjects in the degree. Several criteria must be satisfied when selecting the problem. Specifically, it must (1) be a real world problem; (2) be relevant to the students; (3) require analysis from different perspectives, promoting multidisciplinary solutions and (4) present an engaging challenge throughout the course of the degree.

In addition, this paper describes the implementation of an experience within the Bachelor's degree on Industrial Electronics and Automation Engineering at the Faculty of Engineering Vitoria-Gasteiz, University of the Basque Country (EIVG). This implementation follows a dynamic and active teaching model, the so-called IKD educational model [24], which promotes the adoption of 12 of the 17 SDGs [25]. The chosen problem involved the assessment of the thermal comfort and energy consumption in the EIVG building and the analysis of measures to reduce energy consumption. This problem satisfies all the requirements stated before. In particular, it allows analysis of the problem from the specific perspectives used in every subject while reducing knowledge compartmentalisation.

In order to scaffold the implementation, a multidisciplinary and multi-course itinerary was designed, which included intertwined activities in different subjects using active methodologies. Throughout the itinerary, students delved into their understanding of the SDGs, becoming aware of their importance. Thus, they may also understand the consequences of incorporating these goals into their future professional endeavours. In the presented implementation case, the activities were focused on the following SDGs [26]:

- Good Health and Well-Being (SDG 3);
- Quality Education (SDG 4);
- Industry, Innovation and Infrastructure (SDG 9);
- Sustainable Cities and Communities (SDG 11);
- Responsible Consumption and Production (SDG 12).

Questionnaires are typically used for evaluating engineering students' awareness of sustainability issues [27]. Hence, as part of the methodology, two questionnaires were designed to analyse the achievement of the research questions and validate the presented approach. The first questionnaire, taken in every subject before the SDG activities, measures the previous knowledge of the students about SDGs and their expectations within engineering studies. The second questionnaire, taken in every subject after the SDG activities, measures the students' satisfaction, the degree of SDG achievement perceived by students and the expectations towards undertaking sustainability-related tasks in the future. In the implementation at the EIVG, the questionnaire results proved that the multidisciplinary activities helped students to learn about the SDGs and motivated them to carry out sustainability-related activities in the future.

Thus, the implementation of the methodology achieved several objectives: (1) students acquired knowledge about the SDGs and their relevance to the society, (2) it introduced a transversal point of view to solve engineering problems, (3) students reflected on how they could design and develop sustainability-related projects by applying the knowledge acquired throughout the degree, (4) it visualised that improving sustainability can be part of the students' future professional careers, and (5) students became aware of responsible use of resources—in particular, energy consumption.

The rest of the article is organised as follows. Section 2 introduces some related works and trends aimed at introducing sustainability in HEIs. Section 3 presents a methodology to implement multidisciplinary activities in engineering degrees. Section 4 shows an implementation example aimed at the Bachelor's degree on Industrial Electronics and Automation Engineering. Section 5 analyses students' assessment of the multidisciplinary experience. Finally, Section 6 exposes the conclusions drawn from this work.

## 2. Related Work

The commitment to comply with the UN 2030 Agenda and the SDGs by institutions and society in different countries has resulted in their incorporation into the Agendas of Educational Centres, especially HEIs. Thus, the commitment to the SDGs is included in the information provided by the universities themselves. Observing the main university rankings—QS World University Ranking [28], Times Higher Education Ranking [29] and Shanghai Ranking [30]—it can be verified that the world's leading universities endorse and develop this commitment. In addition, both the QS World University Ranking and the Times Higher Education Ranking present a specific ranking on sustainability or on the

development of the SDGs [31,32]. In this way, the Massachusetts Institute of Technology (MIT), USA [33], embraces the SDGs at both curricular and research levels, highlighting the applied projects in which they participate. The University of Oxford, UK, for its part, launched the SDG Impact Lab [34] in 2021 to help graduate students attain SDGs. Harvard University, USA, on the other hand, raises both the institution's sustainability objectives and their relationship with educational programs from its Office for Sustainability [35]. The University of California, Berkeley, USA, leads the QS Ranking on Sustainability. The UC Berkeley Office of Sustainability presented a study to "Identify the strengths and weaknesses of UC Berkeley sustainability curriculum" and researched the role that HEIs should play in the development of the SDGs [36]. The Western Sydney University, AU, has regained first place in the Sustainability Ranking of the Times Higher Education in 2023. The document *Unlocking Impact. Sustainability Report 2022* [37] highlights not only the meritorious position obtained in the ranking, but also the enduring work across the CORE (Curriculum, Operations, Research and Engagement) framework.

Beyond the institutional scope represented by the universities that lead the rankings, many studies present systematic reviews collecting the results of the SDG implementation experiences in the HEIs. Some examples highlight the advantages that the incorporation of the SDGs provides in the preparation of the future graduates [38–42]. Other works present experiences about the integration of the SDGs into university curricula. For example, the work developed by Mori et al. [43] describes the commitments to the SDGs made by the Royal Melbourne Institute of Technology (RMIT) University, AU, on a university-wide project that began in 2018. The project provides students with the knowledge and skills needed to deal with the challenge that the development of the SDGs supposes in the HEIs, improving sustainability and social inclusion. This study concludes that, although SDGs are being incorporated into the organisation strategies, few of the programs measure and communicate their impact. Mawonde and Togo [44] describe the SDG implementation in the science campus in Johannesburg of the University of South Africa, ZA. This distance education institution has developed many initiatives to promote the SDGs in its near environment. As a result, most of the SDGs are covered by many successful projects supported by the university community. Purcell et al. [45] studied different ways to define sustainability strategies on three universities of different typologies in terms of their status (public or private), size or research dedication. The chosen universities—Plymouth University in UK, American University in Bulgaria and Harvard University in USA—develop many of their sustainability initiatives through "Living Labs" experiences. These Living Labs are open innovation environments that allow innovation, creation, validation, testing and development of new products, systems and services in real-life environments.

Sustainable development is a multidisciplinary problem that requires combining approaches from different disciplines in order to obtain a global comprehension. Through a multidisciplinary approach, students can obtain many skills: problem-solving, analysis and research methodologies, critical thinking and development of integrated perception of these problems. Some of these skills are similar to the "transferable skills" that Assister [46] defined as "the metaskills, the second-order skills which enable one to select, adapt, adjust and apply one's other skills to different situations, across different social contexts and across different cognitive domains".

In his study about multidisciplinary in engineering education, Marques [47] proposed the inter-/multidisciplinary approach as an effective way to counterbalance the excessive specialisation that may be happening in engineering studies. It provides a global vision about the application of engineering methods and techniques: "The increasing specialisation of engineering curricula has led professors, researchers and students to become more and more circumscribed in their specific technical areas. The ensuing fragmentation of knowledge can be related to the difficulties felt by the students in mastering physics, mathematics and engineering topics in an integrated way". Aboelela et al. [48] highlight that multidisciplinary "uses study design and methodology that is not limited to any one

field; and requires the use of perspectives and skills of the involved disciplines throughout multiple phases of the research process”.

In addition to a multidisciplinary approach, many studies have shown the benefits that the use of active methodologies applied to sustainability education provide to students [49–52]. Within these methodologies, PBL is a widely accepted educational method that focuses learning on the student. Mixing this educational methodology, along with a multidisciplinary approach, is a commonly used bundle when introducing sustainability into HEI curricula. This is the case of Hansen et al., who present a study conducted in 2012 by a multidisciplinary group to investigate the possible incorporation of sustainability in engineering and science education at the Faculty of Engineering and Science of Aalborg University, DK [53]. This work describes the methodology of the study and presents its results and some recommendations to the different agents of the faculty. The work in [54] presents a degree on Sustainable Design Engineering at the University of Aalborg that is organised around design projects. In [55], Thomas presents a study focused on the sustainability of education itself. Approaching the field of engineering, Thomas presents an approach to sustainability through design-based learning (DBL) with mechanical engineering students. The study was successful, and the data obtained showed that both the sustainability topic and the applied methodologies favored the development of the students’ abilities. The author also introduced the problems that may arise with the application of this proposal, such as the lack of motivation by the students or difficulty in finding appropriate professors.

Bertel et al. [56] studied the potential of large-scale projects based on PBL, the so-called megaprojects [57]. These megaprojects allow students to work together across programs and semesters to solve complex problems linked to one or more SDGs while respecting the curriculum of the targeted subjects. These megaprojects systematically integrated principles of education for sustainable development (ESD), specifically multi-/interdisciplinarity, at the PBL level. The results showed the potential of the megaprojects to motivate students on issues related to sustainability and to develop important professional competences. In turn, Gupta understands sustainable development as providing sustainable educational programs [58], that is, providing broader access to quality education with experience-value learning opportunities. With this purpose, he proposed the use of PBL and DBL to improve learner-centric, team-based and problem-solving environments in the software engineering course within the Bachelor of Tech-Computer Science and Engineering discipline.

Other authors evaluate how the activities carried out affect the students’ perception of sustainability. In the case of the College of Engineering and Physical Sciences of Aston University, UK, active learning methodologies were applied to carry out an interdisciplinary module aimed at solving complex projects related to sustainable development [59]. For one week (2018–2019), 80 students, supervised by academic and professional staff, worked around real-life problems from Engineers without Borders, UK, in which key knowledge related to SDGs was provided. The initiative was assessed through two questionnaires (one pre-project and another post-project) that considered aspects related to sustainability, teamwork and user-centred design. The results pointed out that students improved their ability to understand others’ viewpoints and their capacity to evaluate the consequences of their professional decisions. Alvarez et al. [60] carried out a study on the Civil Engineering degree at the Faculty of Engineering Bilbao, University of the Basque Country (UPV/EHU). This work illustrated the benefits of the transversal and active-based approach, although it was a smaller experience in terms of number of subjects and courses involved in the project when compared with the present one.

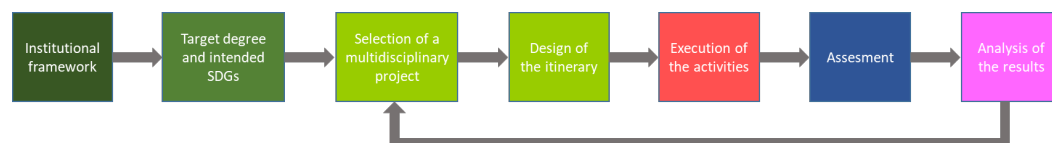
One pioneering and interesting initiative aimed at reorienting university curricula to address sustainability was the RUCAS-Tempus project initiative [61]. This project developed a methodology to support the introduction of Education for Sustainable Development issues in Higher Education. The project followed a multidisciplinary and systemic approach by adopting three stages: (1) what to teach and how to teach it; (2) how to design and implement a course and (3) how to ensure that students are learning what is being

expected. It promoted changes in the sustainability curriculum in 12 universities from 8 countries in which almost 4000 students participated. As an application example, this methodology was used to design an M.Sc. programme on ICT in education for sustainable development [62]. More recently, the DeCoRE+ methodology [63] was designed to help the transition from theory to praxis when curriculum adaptations are made. This methodology includes the phases of Diagnostic Evaluation, Deconstruction, Construction, Reconstruction, Implementation and Summative Evaluation that allow the redefinition of the curriculum and the evaluation of the results.

Therefore, it can be concluded that HEIs play a relevant role in the implementation of the SDGs, mainly due to their involvement in teaching, researching and knowledge transfer. In the case of engineering degrees, solving SDG issues implies multidisciplinary, avoiding the fragmentation of subjects that has traditionally marked their curricula. For this reason, it is necessary that a transversal and holistic approach encompasses several subjects by intertwining concrete activities in engineering degrees. In this context, PBL has proven to be a suitable approach to develop multidisciplinary projects. Most analysed papers describe specific implementations in concrete institutions, which can hardly be replicated in other institutions or degrees. Therefore, it would be useful to (1) have a methodology to guide the incorporation of sustainability concerns in the curriculum in engineering degrees and (2) include mechanisms to assess how the actions carried out influenced students.

### 3. Methodology

This section presents a methodology aimed at introducing sustainability issues in the curricula of engineering degrees by means of multidisciplinary experiences. Figure 1 shows the major implementation stages. These stages are described in higher detail below.



**Figure 1.** Implementation stages for the multidisciplinary activity.

#### 3.1. Institutional Framework

An increasing number of universities are developing different programs aimed at raising student awareness of sustainable development. In most cases, these programs promote methodological changes aimed at making students more active in their learning and offer generic frameworks for implementing activities aimed at introducing SDGs in Higher Education. It is convenient to adapt the multidisciplinary activity to align with the institutional framework.

#### 3.2. Target Degree and Intended SDGs

The contents and skills to be acquired during the target degree must be analysed in detail before designing multidisciplinary experiences. Students of engineering degrees should learn to design and create new systems aimed at solving problems demanded by society. Unfortunately, teaching others how to design these new systems is not an easy task. In practice, this is a common problem for all engineering degrees [15]. In addition, the proposed projects must help students to delve into their understanding of the SDGs, or a set of SDGs, and, at the same time, make them aware of their importance. Finally, one must analyse how students are expected to incorporate the selected SDGs into their future professional endeavours.

#### 3.3. Selection of a Multidisciplinary Project

This is a key stage, since selecting a “good” multidisciplinary project is a challenging issue, as it must fulfill several requirements simultaneously. Namely, the project should (1) focus on a real world problem, so students may learn from their experience to face future

professional tasks; (2) be relevant to the students, in order to motivate them; (3) require analysis from different perspectives, to promote multidisciplinary solutions that intertwine several activities and (4) present an engaging challenge throughout different courses of the degree. In all, the selected multidisciplinary project becomes a common thread to acquire different skills along several subjects of the degree. One important issue is that the multidisciplinary project must be able to introduce SDGs coherently. In this sense, the work in [9] proposes six transformations that may be used to identify problems that group several SDGs.

### 3.4. Design of the Itinerary

In order to scaffold the experience, after choosing the project, it is necessary to carefully select the subjects in which it is developed. The definition of the itinerary allows analysis of a multidisciplinary problem from the different perspectives used in every subject. Thus, the itinerary must cover a broad number of subjects along the course of the degree.

### 3.5. Execution of the Activities

This stage involves the design and execution of all designed activities for every subject. Again, this is a challenging issue for several reasons: (1) frequently, the syllabus of the subjects are very tight, making it difficult to not omit important contents and (2) all activities must be intertwined within the multidisciplinary project. For these reasons, the authors recommend leaving flexibility to the coordinators of every subject to design activities of different duration. The proposed activities are included in the syllabus of every subject as new tasks. Typically, their weight in the final qualification of the subject is proportional to the number of classroom hours

### 3.6. Assessment

As part of the methodology, the authors designed two questionnaires for assessing whether the multidisciplinary experience produced changes in the student's perception about sustainability issues and the SDGs. The first one is taken before the activity (pre-activity, see Appendix A) and the second one after the activity (post-activity, see Appendix B). These questionnaires must be issued in the classroom to all participant students in every subject. Since it is important to obtain sincere information about the experience, the responses to the questionnaires must be treated strictly anonymously. In order to guarantee the anonymity, confidentiality and privacy of the data obtained, the pre- and post-activity questionnaires were designed in such a way that they only collected data directly related to the students' perception about the activities as well as about sustainability issues.

The pre-activity questionnaire measures the generic knowledge about the selected SDGs. In addition, it collects the perception of the students about the importance of introducing the SDGs in engineering degrees in general, as well as in every particular subject. Table A1, in Appendix A, shows the pre-activity questionnaire used in the implementation example within the Bachelor's degree on Industrial Electronics and Automation Engineering at the EIVG. This questionnaire may be used as a template to design questionnaires adapted to other implementations, which may involve different activities and SDGs. With the purpose of guiding the implementation stage, the questions that depend on the specific project are highlighted in blue, those dependent on the institution are marked in orange and those related to the SDGs covered by the project are emphasised in green.

The post-activity questionnaire measures students' satisfaction with the activities carried out in every subject. In particular, it evaluates the connection of the proposed activity with the selected SDGs. Also, it collects the students' opinions about performing sustainability-related tasks in their future professional careers. Table A2, in Appendix B, shows the post-activity questionnaire, used in the implementation example. Again, this questionnaire could be adapted for other implementations involving different activities and SDGs. Those parts that depend on the proposed project are highlighted in blue, whereas those related to the SDGs covered are emphasised in green.

A Likert scale of 7 was used in both questionnaires to provide a good graduation degree in the responses. All responses indicate students' degree of agreement with the proposed questions, which range from 1, meaning the lowest value of the response (totally disagree), to 7, meaning the maximum value (totally agree).

### 3.7. Analysis of the Results

Designing and implementing multidisciplinary experiences that intertwine several subjects is challenging, especially when it is required (1) to increase the knowledge about the SDGs after the activities; (2) to be close to the students' experiences to engage them and (3) to make students aware of how to apply learned skills in their future professional life. The authors assess the completion of the research questions stated in the Section 1 by analysing selected questions of the questionnaires issued to the students.

## 4. Implementation Example

The presented methodology was followed to implement a multidisciplinary project that was aimed at introducing sustainability issues into the Bachelor's degree on Industrial Electronics and Automation Engineering at the EIVG (UPV/EHU). The next subsections describe the implementation details at every stage.

### 4.1. Institutional Framework

In the UPV/EHU, the IKD educational model supplies a framework by means of the so-called i3KD educational innovative projects [24]. These projects can be used to integrate SDGs into the competences of different degrees following the EHUagenda 2030 for sustainable development [25]. In this work, an i3KD project provided the framework to integrate some SDGs in a multidisciplinary way into the competences of the Bachelor's degree on Industrial Electronics and Automation Engineering taught at the EIVG Faculty, UPV/EHU.

### 4.2. Target Degree and Intended SDGs

One of the objectives of the selected degree is aimed at developing industrial applications by means of creating full systems that involve designing and programming electronic systems under the Industry 4.0 paradigm. Throughout the degree, students obtain a solid background on several areas such as computing, networking, control engineering, automation, electronic systems and instrumentation. In addition, students acquire fundamental concepts of other domains such as thermal engineering, electrical technology or mechanical systems.

The knowledge acquired in this degree has practical applications in strategic sectors that use electronics and automation devices intensively, such as machinery, automotive, aeronautics or energy production and management systems. It also may be applied to other fields like medicine, agriculture or traffic-management systems. Although a broad number of SDGs may be related to the students' future professional careers, the multidisciplinary activity is required to be focused on the following SDGs:

- Good Health and Well-Being (SDG 3);
- Quality Education (SDG 4);
- Industry, Innovation and Infrastructure (SDG 9);
- Sustainable Cities and Communities (SDG 11);
- Responsible Consumption and Production (SDG 12).

These SDGs are mostly covered in one of the transformations proposed in [9], namely, the third one, which addresses energy efficiency in buildings and constructs.

### 4.3. Selection of a Multidisciplinary Project

The proposed multidisciplinary project stemmed from the idea of incorporating into the curriculum of the target degree the outcomes of two previous projects developed by the authors. These projects were carried out under the Campus Bizia Lab (CLB) program,

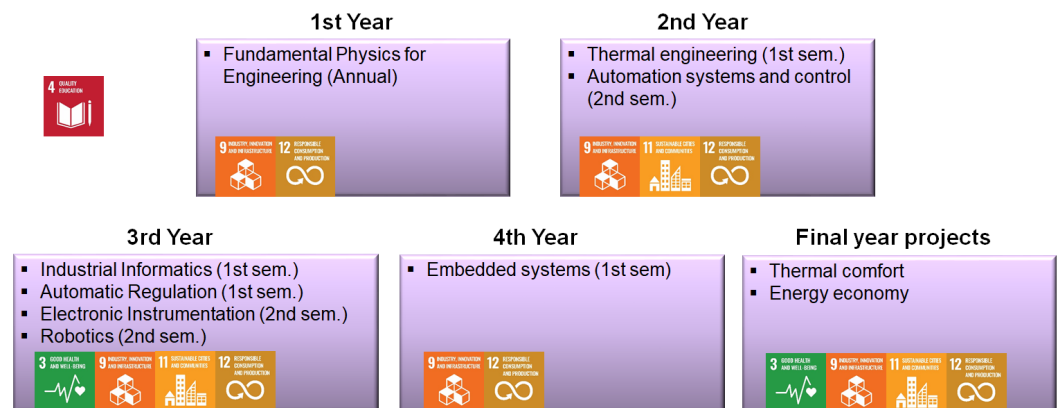
aimed at improving sustainability at UPV/EHU. Particularly, they involved optimising the consumption of energy at the EIVG and implementing measures to improve the sustainability of the thermal system of the EIVG. The main objective of the proposed project was for students to tackle the challenge of analysing and improving the sustainability of the EIVG building. Thus, students were expected to perform the following actions: (1) to analyse energy consumption, (2) to evaluate thermal comfort, (3) to reduce unnecessary consumption, (4) to raise awareness among the university community and (5) to propose concrete actions that could be applied to other public buildings.

The authors considered this project to be an appropriate challenge to introduce sustainability-related actions into undergraduate teaching through active methodologies. The selection of the problem presented to the students satisfies the requirements stated above, including the capability of serving as glue to group the selected SDGs, as stated above in the subsection *Target degree and intended SDGs*. Furthermore, it allows students to (1) acquire knowledge about the SDGs and their relevance; (2) analyse an engineering problem in a transversal way; (3) make a reflection on how design and develop sustainability related projects with their skills; (4) visualise sustainability as part of their professional future activities and (5) be aware of responsible use of resources.

#### 4.4. Design of the Itinerary

In this experience, an itinerary across the four academic years of the Bachelor's degree on Industrial Electronics and Automation Engineering is proposed (see Figure 2). This itinerary must coherently combine the chosen SDGs along several subjects. In the implementation example, the problem of improving energy efficiency in public buildings was chosen. Thus, the proposed itinerary involved subjects related to energy consumption, measurement and control of mechanical devices. This itinerary is expected to grow in the future by including additional subjects such as electrical consumption and the sources used for generating required energy.

This itinerary allows, optionally, the completion of final degree projects related to thermal comfort and energy economy topics.



**Figure 2.** Itinerary along the degree on Industrial Electronics and Automation Engineering.

Figure 2 also presents the SDGs that were considered most relevant in each academic year. SDG 4, Quality Education, concerns the whole itinerary; this is why it was not assigned to a specific academic year.

#### 4.5. Execution of the Activities

Table 1 presents the time, in hours per subject, that students spent in the classroom performing the proposed activities in the implementation during the selected degree. All proposed activities analysed the problem from different perspectives and depth, focussing on the following tasks: (1) analysis of the energy consumption; (2) design of monitoring and

controlling systems and (3) selection of electronic devices, including sensors and actuators, as well as monitoring and control platforms. Appendix E describes in detail every subject and the activities taken.

**Table 1.** In-class hours to carry out the proposed activities of the educational innovative project.

| Subject                             | Year | Semester | # of Class Hours |
|-------------------------------------|------|----------|------------------|
| Fundamental Physics for Engineering | 1st  | Annual   | 4                |
| Thermal Engineering                 | 2nd  | 1st      | 6                |
| Automation Systems and Control      | 2nd  | 2nd      | 4                |
| Industrial Informatics              | 3rd  | 1st      | 30               |
| Automatic Regulation                | 3rd  | 1st      | 4                |
| Electronic Instrumentation          | 3rd  | 2nd      | 6                |
| Robotics                            | 3rd  | 2nd      | 8                |
| Embedded Systems                    | 4th  | 1st      | 4                |

Most activities were carried out in laboratory sessions, but some of them required support from several lectures to explain certain concepts in the classroom.

#### 4.6. Assessment

To guarantee that they only considered the opinions of students taking part in the activities, questionnaires were issued in the classroom. Before starting the activity, students were informed about the reasons for this research and the voluntary nature of the surveys. Throughout the process, the confidentiality of the information collected was adequately safeguarded.

The pre-activity questionnaire measured the initial knowledge about SDG 3 (Good Health and Well-Being), SDG 4 (Quality Education), SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities) and SDG 12 (Responsible Consumption and Production). It also collected the opinions of the students about the contribution of every particular subject to the selected SDGs. This questionnaire is available in Appendix A, in Table A1.

The questionnaire taken after the activity measured students' satisfaction with the activities carried out, as well as the connection of the proposed activity with the selected SDGs. Finally, it collected the opinions of the students about carrying out sustainability-related tasks in their future professional careers. All questions are available in Appendix B, Table A2.

#### 4.7. Analysis of the Results

The results obtained after the multidisciplinary experience were, in general, positive since (1) the implementation incremented students' perception towards the SDGs; (2) students considered that the proposed activities were close to their experiences; (3) the evaluation of the activities was positive in general and (4) students considered that sustainability could become their future professional task. These results are analysed in detail in Section 5.

### 5. Results and Discussion

This section presents the results obtained from the questionnaires taken before and after the multidisciplinary activities in each subject and discusses the results obtained during the project implementation. Students responded while present in the classroom to the questionnaires, in the first and last sessions of the activities taken in every subject. The objectives of both questionnaires are described in Section 3.6. Questionnaires are available in Appendices A and B, respectively.

#### 5.1. Questionnaire Results

The pre-activity questionnaire was answered 360 times in 8 subjects, while the post-activity questionnaire was answered 285 times. It can be noted that the number of responses

to the questionnaire taken after the activity is lower than the number before the activity. This happened because some students reduced their attendance to the lectures at the end of the semester, which is a common situation in the EIVG. We consider that the number of responses obtained is meaningful. Table 2 summarises the number of enrolled students and questionnaire responses per subject. The summary of responses to the questionnaires taken before and after the activity are available in Appendix C, Table A3, and Appendix D, Table A4.

**Table 2.** Number of enrolled student per subject and responses to the questionnaires before and after the SDG activity.

| Subject                             | Year | Enrolled Students | # of Questionnaires Pre-Activity | # of Questionnaires Post-Activity |
|-------------------------------------|------|-------------------|----------------------------------|-----------------------------------|
| Fundamental Physics for Engineering | 1st  | 196               | 155                              | 87                                |
| Thermal Engineering                 | 2nd  | 70                | 25                               | 15                                |
| Automation Systems and Control      | 2nd  | 88                | 75                               | 59                                |
| Industrial Informatics              | 3rd  | 36                | 31                               | 31                                |
| Automatic Regulation                | 3rd  | 31                | 23                               | 23                                |
| Electronic Instrumentation          | 3rd  | 36                | 25                               | 24                                |
| Robotics                            | 3rd  | 44                | 21                               | 21                                |
| Embedded Systems                    | 4th  | 10                | 5                                | 5                                 |

The next subsections describe in higher detail the characteristics of every subject as well as questionnaire-execution issues. The responses to some selected questions, before and after the execution of the activities, are also presented for each subject.

#### 5.1.1. Fundamental Physics for Engineering

This subject is taken by a broad number of students since it is common to several Bachelor's degrees in Industrial Engineering (namely, Industrial Electronics and Automatics, Mechanical Engineering and Industrial Chemical). As part of the implementation, a special laboratory session was included to introduce the SDGs to the students and discuss how students could use their knowledge to achieve them. The surveys provided to the students were carried out during laboratory sessions.

As expected, students did not know the SDGs very well before the activity. After the introductory session, the questionnaire results proved that they knew all SDGs much better in general (Q1A: 2.9; Q1B: 4.1), as well as all selected SDGs (Q3B–Q7B). In general, students considered that the activity included the SDGs appropriately (Q13B: 4.4). This activity made students aware of the importance of achieving thermal comfort while ensuring appropriate heating usage (Q10B: 4.4). Finally, students considered that their future professional tasks could be connected to enhancing sustainability and achieving the SDGs (Q12B: 4.6).

#### 5.1.2. Thermal Engineering

This subject is also common to several Bachelor's Degrees in Industrial Engineering, being taken by a broad number of students. In the subject of Thermal Engineering, the proposed activity was carried out during the last six weeks of the semester. Students worked in groups, thus promoting the development of transversal competences such as collaborative work and critical thinking.

The results of the pre-activity and post-activity surveys showed that the majority of the students who completed the task considered that this activity connected especially well with the following SDGs: SDG 9 (Q4B: 4.7), SDG 11 (Q5B: 4.4) and SDG 12 (Q6B: 4.2). They also considered appropriate the way that these SDGs had been integrated into the subject (Q8B: 5.1). In addition, students thought that this activity allowed them visualising how to contribute to achieving the SDG targets from engineering studies (Q9B: 5.1). Overall, the majority of students considered the activity as a good example to develop the SDGs through the skills and competences of the subject.

### 5.1.3. Automation Systems and Control

This subject is also taken by a broad number of students since it is common to several Bachelor's degrees in Industrial Engineering. According to the results of the survey, it can be concluded that, at the beginning of the activity, students had a general understanding of the SDGs (Q1A: 4.4). This might be because this subject was taught during the second semester and most students had already taken the Thermal Engineering subject during the first semester of the same academic year. They considered that achieving the SDGs affected them (Q8A: 5.1) and, consequently, should be included in engineering degrees (Q9A: 5.2) by means of experiences close to students (Q2A: 5.2). Students felt that this particular subject might contribute mostly to achieve SDG 9 (Q16A: 5.4).

After the activity, students considered that they had a better understanding of the SDGs in general (Q1B: 4.6), and, in particular, of SDG 9 (Q4B: 5.0), SDG 11 (Q5B: 4.9) and SDG 12 (Q6B: 4.8). Students felt that this subject could contribute to improve sustainability (Q7B: 5.2), and considered that, overall, the inclusion of the SDGs in the subject was appropriate (Q13B: 5.1). They also thought that the activity provided a good example to enhance sustainability (Q9B: 5.0), raising awareness of the balance between achieving thermal comfort and ensuring appropriate heating usage (Q10B: 5.1).

### 5.1.4. Industrial Informatics

This subject is taken in the third year of the degree, in the first semester. It can be observed that students had a moderate general understanding about the SDGs (Q1A: 3.7). However, they considered that these goals affect them personally (Q8A: 5.1) and, consequently, should be included in the engineering studies (Q9A: 5.5). In particular, they pointed out that sustainability-related aspects, such as responsible use of resources, should be considered in the design of engineering solutions (Q11A: 6.3), preferably by means of activities close to students' interests (Q10A: 5.1). Before the activity, they felt that this subject could contribute particularly to SDG 9 (Q16A: 5.8).

After the activity, they considered that the tasks proposed in this subject connected best with SDG 9 (Q4B: 4.6). They found that it was appropriate to integrate the proposed SDGs in the subject (Q8B: 5.1) since the activity carried out in class raised awareness of achieving thermal comfort while ensuring appropriate heating usage (Q10B: 5.1). Finally, students felt that their future professional tasks could be somehow related to enhancing sustainability (Q12B: 5.1). In general, students said that the overall inclusion of the SDGs in the subject was appropriate (Q13B: 4.8).

### 5.1.5. Automatic Regulation

This is also a third-year, first-semester subject. Before the activity, students indicated that they knew SDG 9, SDG 11, and SDG 12 best, with values of 4.1 (Q5A), 4.1 (Q6A) and 4.0 (Q7A), respectively. After the activity, the students declared that the proposed activity connected the course with the aforementioned SDGs with values of 5.0 (Q4A), 4.8 (Q5A) and 4.5 (Q6A), respectively, which shows a positive impact of the activity among the students. These results prove that students deepened their knowledge of these SDGs and that there is a direct link between the Automatic Regulation course and the mentioned SDGs.

The initial expectation of the students regarding how much the Automatic Regulation course can contribute to raise awareness of the SDGs in general is 4.9 (Q13A); at the end of the intervention, the students considered it adequate (with a 5.3 in Q13B), in terms of how the SDGs had been introduced in the course. In the opinion of the authors, this result indicates that the activity proposed in the Automatic Regulation course contributed positively to raise awareness and train students in the SDGs. Finally, it is noteworthy that students considered that their future professional tasks could be related to sustainability, with a mark of 5.5 (Q12B).

### 5.1.6. Robotics

This subject is taught during the third year, second semester. Consequently, most of the students took it after Industrial Informatics and Automatic Regulation. The results of the

questionnaires proved that the activity developed in this subject incremented knowledge about the SDGs in general (Q1A: 4.3 vs. Q1B: 4.6). In particular, it increased the knowledge of most of the selected SDGs: SDG 3 (Q3A: 4.0 vs. Q2B: 4.8); SDG 4 (Q4A: 4.0 vs. Q3B: 4.1) and SDG 11 (Q6A: 4.5 vs. Q5B: 4.8).

In the pre-activity questionnaire, students considered that achieving SDGs was a matter that affected them (Q8A: 5.0) and, consequently, that they should be included in the engineering degrees (Q9A: 5.5) by means of activities close to student interests (Q12A: 6.0). Finally, they considered that Robotics was mostly connected to SDG 9 (Q16A: 5.7). In the post-activity questionnaire, students felt that the Robotics course could contribute to improve sustainability (Q7B: 5.3) and that the proposed SDGs were appropriately integrated in the subject (Q8B: 5.3). Again, after the activity, students considered that their future professional tasks could be linked to sustainability issues (Q12A: 5.1).

#### 5.1.7. Electronic Instrumentation

Most students took this subject in parallel with Robotics, during the second term of the third academic year. The responses to the questionnaires showed that, similarly to other subjects, the degree of general knowledge about the SDGs was incremented after the activity: 3.6 (Q1A) vs. 5.1 (Q1B). The same happened with all the selected SDGs: SDG 3 (Q3A: 3.5 vs. Q2B: 4.7); SDG4 (Q4A: 3.8 vs. Q3B: 4.2); SDG 9 (Q5A: 4.1 vs. Q4B: 4.8); SDG 11 (Q6A: 3.9 vs. Q5B: 4.8) and SDG 12 (Q7A: 3.6 vs. Q6B: 4.7). Additionally, they considered that it would be necessary to introduce activities close to students' interests (Q12A: 5.3).

The post-activity questionnaire shows that the contents of this subject could contribute to improve sustainability (Q7B: 5.6) and that it was appropriate to integrate SDGs in the subject (Q8B: 5.6). Students considered that, overall, the inclusion of the SDGs in this subject was appropriate (Q13B: 5.4) since it allowed visualisation of how to contribute to improving the SDGs through engineering studies (Q11B: 5.1).

#### 5.1.8. Embedded Systems

This is an elective subject taken during the first semester of the fourth academic year of the degree. This is a quite specific subject that introduces common tools used in industry. In the Industrial Electronics and Automation Engineering degree, students may choose between attending some elective subjects or undertaking practical work in local companies, which is the most common option. For this reason, the number of students enrolled in this elective subject was small.

The results of the questionnaires were in parallel with other subjects. In general, the activity increased the general knowledge about the SDGs (Q1A: 2.4 vs. Q1B: 4.8). The same happened regarding the selected SDGs: SDG 3 (Q3A: 2.4 vs. Q2B: 4.2); SDG 4 (Q4A: 2.0 vs. Q3B: 4.6); SDG 9 (Q5A: 2.6 vs. Q4B: 4.6); SDG 11 (Q6A: 3.2 vs. Q5B: 4.4) and SDG 12 (Q7A: 2.2 vs. Q6B: 4.8). In addition, they would welcome the introduction of activities close to students' interests (Q12A: 6.0), particularly connected with the responsible use of resources (Q11A: 5.2).

The post-activity questionnaire showed that students believed that this subject could contribute to improving sustainability (Q7B: 5.0) and that the inclusion of the SDGs by means of the proposed activity was appropriate (Q13B: 5.2). Finally, the activity helped students to consider sustainability as a possible future professional domain (Q12B: 5.0).

#### 5.1.9. Final-Year Project

Several final degree projects continued some of the tasks identified in the different subjects involved in this implementation. These final degree projects developed more deeply some issues related to the proposed case study. This approach enriched the activities of the innovative educational project and, at the same time, allowed students to learn how to continue until reaching, for example, a final product that could be marketed. As a matter of example, one final degree project already carried out involved the evolution of some of the activities proposed to the students in the multidisciplinary itinerary.

In particular, it involved using the OpenFog standard (IEEE 1934-2018) to combine artificial intelligence techniques, particularly Fuzzy logic, with IoT technologies to improve indoor comfort, safety and environmental conditions inside the Faculty building. The results were published in [64,65].

## 5.2. Discussion

The presented implementation illustrated the application of the methodology to materialise the introduction of several SDGs (namely, SDG 3, SDG 4, SDG 9, SDG 11 and SDG 12) in the curricula of the Bachelor's degree on Industrial Electronics and Automation Engineering in the Faculty of Engineering of Vitoria-Gasteiz (UPV/EHU). For this purpose, a multidisciplinary project, involving eight activities during the degree, as well as, optionally, the final degree project, was designed.

The results of the pre-activity questionnaires proved that, before doing the activities, students had a moderate understanding of the SDGs in general (Q1A: 3.6/7.0) and about the particular SDGs considered in this implementation (Q3A–Q7A).

Students perceived that the achievement of these goals had important influence in their lives (Q8A: 4.7/7.0) and, consequently, should be introduced into their engineering degrees (Q9A: 4.8/7.0). However, they considered that, currently, SDGs were superficially addressed by the UPV/EHU (Q10A: 3.9/7.0). Students felt that sustainability-related topics, such as responsible use of resources, should be included in the design of engineering solutions (Q11A: 5.2/7.0), preferably by means of activities (projects or problems) close to the students' experiences (Q12A: 5.5/7.0). In particular, they showed the highest interest in SDG 9 (Q16A: 5.1/7.0).

The results of the post-activity questionnaires (see Appendix D, Table A4) showed that, in general, the proposed activities allowed a better understanding of the SDGs in general (Q1B: 4.4/7.0). Students also considered that the proposed activities connected the subjects with the SDGs selected in the project relatively well (Q2B–Q6B). In most cases, the values obtained for the questions related to these specific SDGs (Q2B–Q6B) increased when compared to the values obtained before carrying out the activities (Q3A–Q7A). Particularly, they considered that the presented activities had a special connection with SDG 9 (Q4B: 4.7/7.0). In fact, this was precisely the original motivation of the CBL project from which this educational innovative project stemmed. In general, students considered that the contents of the subjects could contribute to improve sustainability (Q7B: 4.9/7.0). Moreover, students felt that the proposed activities allowed for visualisation of how to contribute to improving the SDGs through engineering studies (Q11B: 4.7/7.0). Actually, the overall inclusion of the SDGs in these subjects was considered appropriate (Q13B: 4.8/7.0). Finally, according to the responses from the students, they thought that their future professional endeavors could involve enhancing sustainability issues and achieving the SDGs (Q12B: 4.9/7.0).

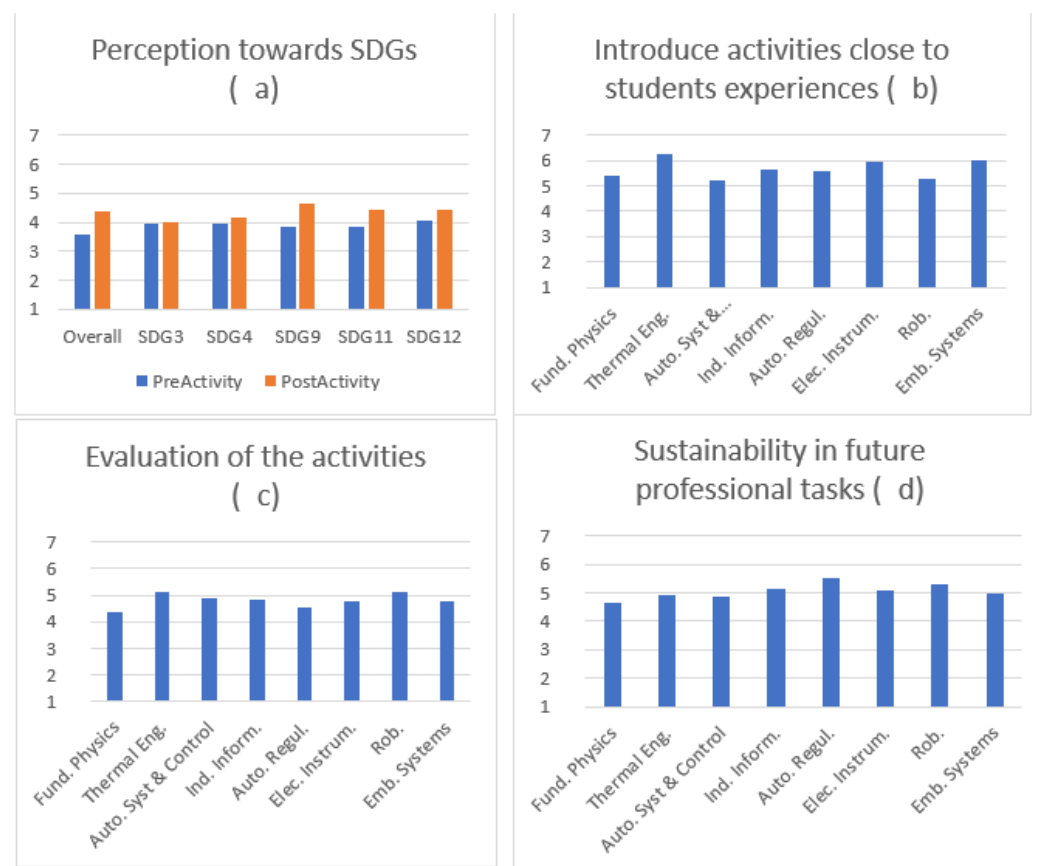
Figure 3 summarises the major findings obtained after analysing the results of selected questions of the questionnaires. The responses to the questionnaires after the implementation allow the authors to answer the research questions:

**RQ1:** How to introduce the SDGs in the curricula of engineering degrees by means of concrete activities. In the implementation example, several SDGs (namely, SDG 3, SDG 4, SDG 9, SDG 11 and SDG 12) were included in the curriculum of the Bachelor's degree on Industrial Electronics and Automation Engineering by means of activities intertwined in several subjects. Figure 3a comprises all responses to questions Q1A and Q1B, related to the general understanding towards the SDGs before and after the concrete activities. Also, when students were asked for particular SDGs before (questions Q3A–Q7A) and after (questions Q2B–Q6B) the obtained results proved that the project implementation always achieved an increment in all SDGs and, particularly, with some of the selected SDGs, namely, SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities) and SDG 12 (Responsible Consumption and Production). From these responses, the authors conclude that implementing this kind of multidisciplinary activity,

covering several subjects, is a suitable way of introducing the SDGs in the curricula of engineering degrees;

**RQ2:** How multidisciplinary experiences, which intertwine several subjects, should be designed to engage students. Figure 3b shows the responses to question Q12A in all subjects. Obtained results confirm that students clearly demand the introduction of activities related to their interests in order to include sustainability in the curricula since all responses have high values. This encourages academic staff to find engaging activities. Figure 3c shows that students consider that the inclusion of the SDGs by means of the intertwined activities carried out in every subject was appropriate (question Q13B). This may be used as an indicator to show that the presented methodology and the proposed activities engaged students;

**RQ3:** How to make students aware that the skills acquired during the degree may help them to design and develop sustainability-related projects in their future professional activities. Finally, question Q12B, shown in Figure 3d, has been used as an indicator of the students' awareness towards using the skills acquired during the degree in their future tasks. In general, the responses were positive, especially in the most technical subjects, taught in the third and fourth years (i.e., Industrial Informatics, Automatic Regulation, Electronic Instrumentation, Robotics and Embedded Systems). From the obtained results, the authors conclude that the activities, based on real problems, close to the students, motivated them to consider sustainability-related tasks as a possible future professional activity.



**Figure 3.** Summary of the mean values obtained from selected responses of the questionnaires. Students' responses always range from 1 to 7. (a) shows the overall perception about SDGs as well as about the selected SDGs, before and after the activities. (b) shows that students demand activities close to their experiences. (c) shows the overall evaluation of the activities carried out in each subject. (d) shows the perception by students towards carrying out sustainability related tasks in their future professional activity.

Obtained results proved that, in general, the implementation of the multidisciplinary experience was successful. However, it is important to note, that, although the project is designed to cover the whole degree, the 2022/23 academic year was the first time it was carried out. Activities in all courses were simultaneously implemented during the same academic year. Consequently, the responses obtained from the questionnaires are not necessarily correlated with the expected progression along the degree itinerary.

## 6. Conclusions and Future Work

The introduction of sustainability issues in engineering degrees is a complex task and, currently, it is still incipient in a broad number of Higher Education Institutions. One of the reasons is that sustainability applications in engineering are typically multidisciplinary and the current design of the curricula compartmentalises the knowledge into subjects.

In this scenario, it is necessary to materialise the introduction of the SDGs in the curricula of engineering degrees following a systemic approach (RQ1); design multidisciplinary experiences, intertwining several subjects, which engage students (RQ2) and make students aware that the skills acquired during the degree may help them to design and develop sustainability related projects in their future professional activity (RQ3).

This article tries to guide academic staff to materialise the introduction of sustainability-related multidisciplinary experiences by means of concrete activities that group several SDGs in a coherent way. For that purpose, it presents some principles and guidelines that may help professors and instructors to design new educational activities.

Since professors and instructors may benefit from knowing multidisciplinary experiences carried out in different institutions, this work also presents the implementation of a multidisciplinary experience into the Bachelor's degree on Industrial Electronics and Automation Engineering at the EIVG (UPV/EHU) throughout the 2022/23 academic year. This experience was aimed at increasing knowledge about the SDGs and proposing specific actions to contribute to their achievement. The authors used active methodologies for implementing the activities since, according to the literature, they have been found particularly suitable for developing the concept of sustainability in educational programs. The authors selected a problem close to the students' context, following recommendations for implementing active methodologies, since this facilitates their understanding. Specifically, the authors chose the problem of analysing the thermal comfort in the EIVG Faculty building and proposing actions to optimise energy consumption, this background allows us to introduce one of the transformations proposed in [9]. Namely, it is related to decarbonisation of energy systems by improving energy efficiency and final energy use in public buildings.

Along this experience, the authors designed an educational itinerary across eight courses throughout the four academic years of the degree program, involving issues related to energy consumption, measurement and control of mechanical devices. Thus, the proposed problem became the common thread to introduce multidisciplinary and gain a deeper understanding about one problem from different perspectives. The presented approach reproduces in the classroom the conditions that students will face in their future professional work, where they will have to tackle tasks holistically. Thus, the compartmentalisation of knowledge in separate courses is reduced. Various activities of different duration and complexity were proposed in each of the involved courses, ranging from 4 to 30 classroom hours. These activities were aimed at solving specific problems using active methodologies.

In each course, two surveys were conducted: one at the beginning of the activity to assess students' perception towards the SDGs and their connection to the taught subjects, and another at the end of the activity to evaluate the conducted activity. The analysis of the questionnaire results proved that the understanding of the SDGs increased after performing the multidisciplinary activities (RQ1), that the proposed activities, which were close to the experience of the students, were engaging (RQ2) and that these activities motivated students to consider that sustainability-related tasks may become part of their

future professional activity (RQ3). These results proved that, in general, the implementation of the multidisciplinary experience was successful.

The implementation in the Bachelor's degree on Industrial Electronics and Automation Engineering is a preliminary experience for introducing sustainability-related issues in engineering degrees by means of multidisciplinary activities. Currently, this study presents certain limitations. On one side, it was only implemented during one year and over one engineering degree. After analysing the questionnaire results, the authors consider that the implementation during the first year was successful; however, it is necessary to evaluate a longer implementation period. Also, it would be convenient to test the presented approach in other engineering degrees. Another limitation comes from the fact that, traditionally, the engineering teaching curricula tend to be compartmentalised into subjects, at least in our Faculty. The presented approach tried to mitigate this inconvenience, but the implementation was challenging for several reasons: (1) it should coordinate a broad number of subjects as well as professors and instructors; (2) the syllabus of every subject was very tight, making it difficult to include all important contents and (3) the proposed activities were intertwined within the multidisciplinary project. Other issues may arise when modifications in the syllabus of the subjects are required since the contents are more intertwined.

Overall, this experience is expected to continue for several years and, consequently, it must be able to adapt to new scenarios. Currently, the authors are trying to balance the interrelation among the proposed activities in terms of the number of hours and qualification weight. Ideally, there should also be more subjects involved in order to provide more perspectives of the same problem. At present, the authors are working to include subjects related to electrical technology in the multidisciplinary experience. Finally, the authors consider it important to include not only the technical issues involved in the selected subjects, but also the related social issues.

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**Institutional Review Board Statement:** The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of the Faculty of Engineering of Vitoria-Gasteiz, on 16 May 2022.

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

**Data Availability Statement:** No new data were created or analyzed in this study. Data sharing is not applicable to this article.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## Appendix A. Pre-Activity Questionnaire

This Appendix includes the questions asked in the questionnaire taken in each subject before undertaking the activities proposed in the project. All responses indicate students' degree of agreement with the proposed questions, which range from 1, meaning the lowest value of the response (totally disagree), to 7, meaning the maximum value (totally agree). This questionnaire is aimed at evaluating the degree of knowledge about the SDGs, as well as the experiences of the students.

**Table A1.** Questionnaire taken before the activity.

| #    | Question                                                                                                                                                    |
|------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Q1A  | I have a general understanding of the United Nations' Sustainable Development Goals (SDGs)                                                                  |
| Q2A  | I believe that society shares and embraces these SDGs                                                                                                       |
|      | I am familiar with the following SDGs:                                                                                                                      |
| Q3A  | a. Good Health and Well-being (SDG 3)                                                                                                                       |
| Q4A  | b. Quality Education (SDG 4)                                                                                                                                |
| Q5A  | c. Industry, Innovation, and Infrastructure (SDG 9)                                                                                                         |
| Q6A  | d. Sustainable Cities and Communities (SDG 11)                                                                                                              |
| Q7A  | e. Responsible Consumption and Production (SDG 12)                                                                                                          |
| Q8A  | I believe that the development of these goals personally affects me                                                                                         |
| Q9A  | I think that the engineering studies should include the SDGs                                                                                                |
| Q10A | I believe that currently, UPV/EHU adequately incorporates the SDGs in the engineering degrees                                                               |
| Q11A | I think that sustainability-related aspects, particularly the responsible use of resources, should be considered in the design of engineering solutions.    |
| Q12A | I believe that it is necessary to introduce activities (projects or problems) close to students' experiences to explore how sustainability can be improved. |
| Q13A | I think that the content of THIS SUBJECT could contribute to raising awareness about the SDGs in general.                                                   |
|      | I believe that THIS SUBJECT can contribute to achieving each of the following SDGs:                                                                         |
| Q14A | a. Good Health and Well-being (SDG 3)                                                                                                                       |
| Q15A | b. Quality Education (SDG 4)                                                                                                                                |
| Q16A | c. Industry, Innovation, and Infrastructure (SDG 9)                                                                                                         |
| Q17A | d. Sustainable Cities and Communities (SDG 11)                                                                                                              |
| Q18A | e. Responsible Consumption and Production (SDG 12)                                                                                                          |

## Appendix B. Post-Activity Questionnaire

This Appendix includes the questions asked in the questionnaire taken in each subject after undertaking the activities proposed in the project. All responses indicate students' degree of agreement with the proposed questions, which range from 1, meaning the lowest value of the response (totally disagree), to 7, meaning the maximum value (totally agree). This questionnaire is aimed at evaluating whether the activities taken in every subject have improved the understanding of the SDGs as well as the degree of student satisfaction with the proposed activities.

**Table A2.** Questionnaire taken after the activity.

| #    | Question                                                                                                                                                 |
|------|----------------------------------------------------------------------------------------------------------------------------------------------------------|
| Q1B  | The activity carried out in class allows for a better understanding of the SDGs in general.                                                              |
|      | The proposed activity connects the subject with the following SDGs:                                                                                      |
| Q2B  | a. Good Health and Well-being (SDG 3)                                                                                                                    |
| Q3B  | b. Quality Education (SDG 4)                                                                                                                             |
| Q4B  | c. Industry, Innovation, and Infrastructure (SDG 9)                                                                                                      |
| Q5B  | d. Sustainable Cities and Communities (SDG 11)                                                                                                           |
| Q6B  | e. Responsible Consumption and Production (SDG 12)                                                                                                       |
| Q7B  | I believe that the content of THIS SUBJECT can contribute to improving sustainability.                                                                   |
| Q8B  | I think it is appropriate that the proposed SDGs are integrated into THIS SUBJECT.                                                                       |
| Q9B  | The proposed activity is a good example of how to enhance sustainability and promote the SDGs through the knowledge and skills acquired in THIS SUBJECT. |
| Q10B | The activity carried out in class raises awareness of achieving thermal comfort while ensuring appropriate heating usage.                                |
| Q11B | The proposed activity allows for visualising how to contribute to improving the SDGs through engineering studies.                                        |
| Q12B | I believe that my future professional tasks may be related to enhancing sustainability and achieving the SDGs.                                           |
| Q13B | Overall, I consider the inclusion of the SDGs in THIS SUBJECT to be appropriate.                                                                         |

Appendix C. Results of the Pre-Activity Questionnaire

Table A3. Summary of responses obtained from the questionnaire taken before the activity.

| Subject                             | Q1A         | Q2A | Q3A | Q4A | Q5A | Q6A | Q7A | Q8A | Q9A | Q10A | Q11A | Q12A | Q13A | Q14A | Q15A | Q16A | Q17A | Q18A |
|-------------------------------------|-------------|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|
| Fundamental Physics for Engineering | Average     | 2.9 | 3.6 | 3.4 | 3.6 | 3.3 | 3.4 | 3.7 | 4.4 | 4.4  | 3.9  | 4.9  | 5.4  | 4.3  | 4.1  | 4.7  | 4.3  | 4.4  |
|                                     | Stand. Dev. | 1.7 | 1.3 | 1.9 | 1.9 | 1.8 | 1.8 | 1.9 | 1.5 | 1.7  | 1.4  | 1.5  | 1.7  | 1.3  | 1.5  | 1.5  | 1.6  | 1.5  |
| Thermal Engineering                 | Average     | 4.1 | 4.1 | 4.3 | 4.0 | 4.2 | 4.0 | 4.4 | 4.4 | 4.9  | 4.1  | 5.5  | 6.3  | 3.7  | 4.0  | 5.3  | 5.0  | 5.0  |
|                                     | Stand. Dev. | 1.7 | 1.4 | 1.5 | 1.7 | 1.7 | 1.8 | 1.7 | 1.7 | 1.4  | 1.1  | 0.9  | 1.2  | 1.6  | 1.4  | 1.4  | 1.5  | 1.4  |
| Automation Systems and Control      | Average     | 4.4 | 4.3 | 4.9 | 4.7 | 4.4 | 4.4 | 4.7 | 5.1 | 5.2  | 3.9  | 5.3  | 5.2  | 4.2  | 4.8  | 5.4  | 4.7  | 5.0  |
|                                     | Stand. Dev. | 1.6 | 1.2 | 1.3 | 1.4 | 1.4 | 1.3 | 1.5 | 1.3 | 1.5  | 1.5  | 1.1  | 1.4  | 1.5  | 1.3  | 1.2  | 1.2  | 1.4  |
| Industrial Informatics              | Average     | 3.7 | 4.1 | 4.1 | 4.4 | 4.3 | 4.1 | 4.2 | 5.1 | 5.5  | 3.7  | 6.3  | 5.6  | 3.9  | 4.7  | 5.8  | 4.9  | 4.9  |
|                                     | Stand. Dev. | 1.9 | 1.3 | 1.8 | 1.7 | 1.8 | 2.0 | 1.8 | 1.7 | 0.9  | 1.2  | 0.7  | 1.2  | 1.1  | 1.3  | 0.8  | 1.5  | 1.6  |
| Automatic Regulation                | Average     | 4.5 | 4.4 | 4.3 | 4.4 | 4.1 | 4.1 | 4.0 | 5.3 | 5.3  | 4.3  | 5.3  | 5.6  | 4.9  | 4.1  | 4.2  | 5.7  | 4.7  |
|                                     | Stand. Dev. | 1.7 | 1.2 | 1.6 | 1.7 | 1.5 | 1.6 | 1.7 | 1.2 | 1.1  | 1.3  | 1.3  | 1.4  | 1.3  | 1.5  | 1.7  | 1.1  | 1.5  |
| Electronic Instrumentation          | Average     | 4.3 | 4.2 | 4.0 | 4.0 | 4.6 | 4.5 | 4.5 | 5.0 | 5.5  | 3.9  | 5.7  | 6.0  | 3.7  | 4.0  | 5.7  | 4.7  | 5.0  |
|                                     | Stand. Dev. | 1.7 | 1.2 | 1.6 | 1.8 | 1.5 | 1.5 | 1.6 | 1.2 | 0.9  | 0.8  | 1.3  | 0.9  | 1.2  | 1.7  | 1.5  | 0.9  | 1.4  |
| Robotics                            | Average     | 3.6 | 3.5 | 3.5 | 3.8 | 4.1 | 3.9 | 3.6 | 5.2 | 4.8  | 3.4  | 5.2  | 5.3  | 4.1  | 3.8  | 3.9  | 4.9  | 3.9  |
|                                     | Stand. Dev. | 1.4 | 1.0 | 1.7 | 1.6 | 1.5 | 1.9 | 2.1 | 1.6 | 1.5  | 1.7  | 1.9  | 1.4  | 1.8  | 1.7  | 1.5  | 1.7  | 1.7  |
| Embedded Systems                    | Average     | 2.4 | 2.6 | 2.4 | 2.0 | 2.6 | 3.2 | 2.2 | 4.0 | 4.6  | 2.6  | 5.2  | 6.0  | 3.2  | 3.0  | 4.4  | 2.6  | 3.0  |
|                                     | Stand. Dev. | 0.9 | 1.1 | 1.1 | 1.0 | 1.3 | 1.6 | 1.1 | 1.7 | 1.5  | 1.3  | 0.8  | 2.3  | 1.6  | 2.0  | 1.8  | 1.5  | 1.9  |
| All responses                       | Average     | 4.4 | 4.0 | 4.1 | 4.7 | 4.4 | 4.4 | 4.9 | 5.0 | 4.7  | 4.7  | 4.7  | 4.9  | 4.4  | 4.0  | 4.1  | 4.7  | 4.4  |
|                                     | Stand. Dev. | 1.4 | 1.6 | 1.4 | 1.4 | 1.5 | 1.4 | 1.3 | 1.3 | 1.3  | 1.5  | 1.3  | 1.4  | 1.4  | 1.6  | 1.4  | 1.4  | 1.5  |

Appendix D. Results of the Post-Activity Questionnaire

Table A4. Summary of responses obtained from the questionnaire taken after the activity.

| Subject                             |             | Q1B | Q2B | Q3B | Q4B | Q5B | Q6B | Q7B | Q8B | Q9B | Q10B | Q11B | Q12B | Q13B |
|-------------------------------------|-------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|
| Fundamental Physics for Engineering | Average     | 4.1 | 3.6 | 4.1 | 4.3 | 4.0 | 4.2 | 4.4 | 4.5 | 4.1 | 4.4  | 4.4  | 4.6  | 4.4  |
|                                     | Stand. Dev. | 1.3 | 1.6 | 1.4 | 1.5 | 1.6 | 1.4 | 1.3 | 1.4 | 1.4 | 1.4  | 1.2  | 1.4  | 1.4  |
| Thermal Engineering                 | Average     | 4.3 | 3.3 | 3.6 | 4.7 | 4.4 | 4.9 | 4.9 | 5.1 | 5.0 | 5.1  | 5.1  | 4.9  | 4.4  |
|                                     | Stand. Dev. | 1.5 | 1.6 | 2.1 | 1.9 | 2.1 | 2.0 | 1.4 | 1.2 | 1.3 | 1.8  | 1.6  | 1.3  | 1.8  |
| Automation Systems and Control      | Average     | 4.6 | 4.5 | 4.7 | 5.0 | 4.9 | 4.8 | 5.2 | 5.1 | 5.0 | 5.1  | 4.9  | 4.9  | 5.1  |
|                                     | Stand. Dev. | 1.3 | 1.3 | 1.2 | 1.3 | 1.3 | 1.4 | 1.1 | 1.2 | 1.2 | 1.3  | 1.5  | 1.2  | 1.3  |
| Industrial Informatics              | Average     | 3.9 | 3.5 | 3.5 | 4.6 | 4.1 | 4.1 | 4.8 | 5.1 | 4.8 | 5.1  | 4.8  | 5.1  | 4.8  |
|                                     | Stand. Dev. | 1.3 | 1.5 | 1.1 | 1.5 | 1.5 | 1.3 | 1.2 | 1.2 | 1.2 | 1.4  | 1.1  | 1.1  | 1.3  |
| Automatic Regulation                | Average     | 4.4 | 3.6 | 3.8 | 5.0 | 4.8 | 4.5 | 5.2 | 5.1 | 5.0 | 5.0  | 4.5  | 5.5  | 5.3  |
|                                     | Stand. Dev. | 1.6 | 1.5 | 1.5 | 1.5 | 1.6 | 1.6 | 0.9 | 1.4 | 1.2 | 1.4  | 1.2  | 1.0  | 1.4  |
| Electronic Instrumentation          | Average     | 4.6 | 4.8 | 4.1 | 4.6 | 4.8 | 4.1 | 5.3 | 5.3 | 4.8 | 4.1  | 4.8  | 5.1  | 4.6  |
|                                     | Stand. Dev. | 1.6 | 1.2 | 1.5 | 1.5 | 1.5 | 1.3 | 1.3 | 1.4 | 1.3 | 2.0  | 1.5  | 1.6  | 1.4  |
| Robotics                            | Average     | 5.1 | 4.7 | 4.2 | 4.8 | 4.8 | 4.7 | 5.6 | 5.6 | 5.1 | 5.0  | 5.1  | 5.3  | 5.4  |
|                                     | Stand. Dev. | 1.2 | 1.5 | 1.5 | 1.2 | 1.1 | 1.3 | 1.1 | 1.4 | 1.3 | 1.2  | 1.1  | 1.5  | 1.3  |
| Embedded Systems                    | Average     | 4.8 | 4.2 | 4.6 | 4.6 | 4.4 | 4.8 | 5   | 4.8 | 4.6 | 4.4  | 4.8  | 5.0  | 5.2  |
|                                     | Stand. Dev. | 0.8 | 0.8 | 0.5 | 0.5 | 1.1 | 0.4 | 0.7 | 1.3 | 0.5 | 0.9  | 1.3  | 1.2  | 1.1  |
| All responses                       | Average     | 4.4 | 4.0 | 4.1 | 4.7 | 4.4 | 4.4 | 4.9 | 5.0 | 4.7 | 4.7  | 4.7  | 4.9  | 4.8  |
|                                     | Stand. Dev. | 1.4 | 1.6 | 1.4 | 1.4 | 1.5 | 1.4 | 1.3 | 1.3 | 1.3 | 1.5  | 1.3  | 1.4  | 1.4  |

## **Appendix E. Itinerary and Activities per Subject**

### *Appendix E.1. Fundamental Physics for Engineering*

This is a core subject that introduces basic physical principles. It is taught annually during the first year. Among other physical concepts, the subject introduces fundamental principles of physics related to thermodynamics and electricity. Additionally, this subject introduces the SDGs and their relationship with energy.

As part of the educational innovation project, a 4 h class activity was designed. Students measured the heat dissipated in an electric resistor using calorimetric techniques. This laboratory activity illustrated that any operating electrical device dissipates energy in the form of heat. This fact represents wasted energy in most cases, contributing negatively to global warming. The proposed activity involved conducting an energy balance to estimate the dissipated energy in the form of “non-useful” energy, using Ohm’s law, Joule’s law and the principle of energy conservation.

### *Appendix E.2. Thermal Engineering*

This is a compulsory semester-long subject taught during the first semester of the second year. The subject builds upon previously acquired thermodynamics concepts. One of the learning objectives is to analyse energy consumption in different applications, promoting their rational and sustainable use, as well as their economic impact.

Within the framework of the educational innovation project, a 6 h class activity is proposed to precisely characterise the behaviour of radiators, which act as heat-emitting units, in order to adjust heat production to the demand for climate control in the most efficient way.

Specifically, the geometry of a heat-emitting unit, as well as the necessary data of the supply water, desired ambient temperature, outdoor temperature and thermal characteristics of surfaces near the radiator were given to the students. The behaviour of a heat-emitting unit was simulated using the student version of ANSYS 2020 R2 Fluent software.

This simulation allowed students to understand the effect of water flow rate and supply temperature on the total emitted power, temperature distribution of the radiator and temperature field of the room’s air.

### *Appendix E.3. Automation Systems and Control*

This is a compulsory semester-long subject taught in the second semester of the second year. The subject introduces basic concepts related to automation and control systems, as well as the commercial industrial devices that perform these tasks.

In this subject, a 4 h class activity was proposed to automate the operation of a ventilation system consisting of a casement window and a CO<sub>2</sub> meter. Limit switch sensors were used to determine the window position, and a safety sensor was also employed. The CO<sub>2</sub> meter allowed monitoring of the air quality in the room. The system had two operating modes: automatic and manual. In manual mode, the window operation was controlled by two command buttons: one to open the window and another to close it. In automatic mode, the window would open or closed based on the measurements obtained from the CO<sub>2</sub> sensor.

For the development of this activity, commercial industrial devices were used. Specifically, Siemens programmable logic controllers (PLCs) and their corresponding programming and simulation tools.

### *Appendix E.4. Industrial Informatics*

This is a compulsory semester-long subject taught in the first semester of the third year. This subject introduces computer tools oriented towards monitoring and control tasks in industrial applications. There is a special emphasis on application programming and communications.

Within the framework of the i3KD project, an activity was designed for students to develop along all the laboratory sessions of the course (30 h). The proposed project applied the PBL methodology to build an IoT system that allows monitoring of some environmental variables in the Faculty of Engineering Vitoria-Gasteiz using existing communications infrastructure based on WiFi technology. Specifically, temperature, humidity, CO<sub>2</sub> and luminosity were monitored in the laboratory classroom where the practical exercises took place. A custom-designed Smart sensor prototype based on Arduino MKR WiFi boards was used. The data acquired by the smart sensors were transmitted to centralised devices, based on Single-Board Computers like Raspberry Pis. These devices evaluated the thermal comfort of the Faculty building at different locations and analysed the energy consumption. A part of the project focused on data analysis of the acquired climatic variables. It involved visualising and analysing, both online and offline, the acquired climatic variables acquired with the Python programming language.

This project aimed to raise awareness among the university community at EIVG about the energy consumption in the classroom.

#### *Appendix E.5. Automatic Regulation*

This is a compulsory semester-long subject taught in the first semester of the third year. This subject introduces concepts of systems theory, including the modelling, analysis and design of control systems.

Throughout the subject, temperature control is used to introduce concepts related to system modelling, analysis and design of automatic controllers. As part of the innovation project, a 4 h activity was conducted to introduce the computer as a control element. This activity was designed to allow students to visualise the characteristics, functions and advantages of digital systems based on microcomputers in process control tasks. The activity also included an initial approach to use a controller to implement a discrete Proportional–Integral–Derivative controller (PID) in a temperature control system. To illustrate the implementation, a pseudo-language program was developed with the objective of implementing a discrete PID.

#### *Appendix E.6. Robotics*

This is a compulsory semester-long subject taught in the second semester of the third year. This subject provides an introduction to general concepts related to mechanical structure, programming, motion generation, robot control, operation of robotic systems and their applications in industrial environments.

As part of the educational innovation project, an 8 h activity was designed. This task continued the activity developed in the Automatic Regulation subject. More specifically, the task involved simulating the design of an automatic control system to open and close the windows of a motorised installation in the laboratory where the practical exercises were conducted. The control system used measurements from CO<sub>2</sub> and temperature sensors to generate the window opening reference within a range of 0 to 40 cm. Subsequently, using a PID controller, the task was to generate the control signal that activated an electric motor to regulate the window opening in the laboratory.

This application serves as a guiding thread to develop the subject's content related to modelling robotic systems and designing PID controllers to control the motion of electric motors that actuate robotic manipulators.

#### *Appendix E.7. Electronic Instrumentation*

This is a compulsory semester-long subject taught in the second semester of the third year. This subject is aimed at designing electronic systems applied to the measurement, monitoring and recording of various physical quantities.

As part of the educational innovation project, a 6 h activity was designed. The objective of the activity was to record the temperature of a room or the outdoors (ambient temperature) over a period of time.

Different temperature sensors were used to measure the temperature. In this way, students were able to verify that, depending on the conditioning and temperature range to be measured, it is more convenient to use certain sensors over others. Students had to consider the desired sensitivity and the trade-off between simplicity and cost of the solution used. In the activity, students were asked to record the data for a full day using National Instruments' LabVIEW 2021 software.

Students followed the procedure described in [15] to condition the sensor and record temperatures. They were asked to analyse the temperature data obtained from different sensors to identify the best sensors for each type of application. This approach aims to encourage students to make reasoned choices when selecting sensors for specific applications.

#### *Appendix E.8. Embedded Systems*

This is an elective semester-long subject taught in the first semester of the fourth year. This subject focuses on the design and implementation of equipment based on modern microcontrollers from the Cortex-M family, using a set of commonly used advanced tools.

In the context of the innovation project, a 4 h activity was designed. The proposed activity aimed to analyse the energy consumption generated by electronic devices that use these microcontrollers, which are commonly used in IoT applications. It also aimed to teach students how to minimise energy consumption by programming different low-power modes. In the initial phase, a theoretical study was conducted to examine the impact on consumption using the energy analyser provided in the STM32CubeIDE programming environment. After that, experimental measurements of the current consumed in different low-power modes were taken. The experimental measurements were compared with the values provided by the manufacturer. During the activity, the direct relationship between the clock speed used in the microcontroller and the energy consumption of the device was observed. Additionally, the different ways to exit low-power modes in each case were analysed.

This approach raised awareness about the consumption of IoT devices and allowed for the estimation of battery life.

This is the only elective subject covered in the project. Typically, these kinds of subjects complement, in a practical way, theoretical concepts already introduced in previous compulsory subjects. Consequently, all students participating in the multidisciplinary project are aware of the problem of the energy consumption of IoT devices, but the students that take this subject learn to use advanced tools to reduce it.

#### *Appendix E.9. Final-Year Project*

The approach followed in the i3KD educative innovation project approach is aimed at having students carry out Bachelor's final degree projects, worth 12 ECTS credits, on the project's theme: thermal comfort and energy economy. Currently, several final degree/Master's projects are being conducted that develop comprehensive solutions based on different technologies. One of these works was an evolution of some of the activities proposed to the students. In particular, it involved using the OpenFog standard (IEEE 1934-2018) to combine artificial intelligence techniques (Fuzzy logic) with IoT technologies to improve indoor comfort, safety and environmental conditions inside the Faculty building. The results were published in [64].

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## Article

# The Contribution of Higher Education to Sustainability: The Development and Assessment of Sustainability Competences in a University Case Study

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**Abstract:** Universities can make a significant contribution to sustainability, and the development of sustainability competences in their graduates should be a key outcome of their courses. We propose an assessment framework for enabling and evaluating the attainment of sustainability competences in University students. We outline its six steps, offering tools on how to assess the alignment of University programs' Learning Outcomes (LOs) to sustainability and how translate them into competences for sustainability. We provide approaches to evaluate existing assessment methods in terms of enabling students to develop and apply their competences, guidance on how to conduct the assessments to collect data on student performance and eventually how to use the data, and evidence collected to evaluate if the students are developing the intended competences. We illustrate the application of the assessment tool in a University case study and we draw conclusions on the evidence it offers to how higher education practitioners can benefit from its use.

**Keywords:** sustainability competences; learning outcomes; assessment tools; ESD; higher education programs



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## 1. Introduction

Education can play a crucial role in the realization of Sustainable Development Goals (SDGs) and the transformational transition to sustainability. This is reflected in SDG 4 and mainly in target 4.7, which explicitly suggests that “by 2030 ensure all learners acquire knowledge and skills needed to promote sustainable development, including among others through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship, and appreciation of cultural diversity and of culture’s contribution to sustainable development” [1]. Educational institutions have a role to play in the transformation required for sustainability to emerge by equipping their graduates with the competences required to become citizens of a sustainable future [2]. The role of higher education institutions is particularly crucial, as they prepare the future professionals with the knowledge and skills, i.e., the competences needed to address pressing challenges such as climate change, violent conflict, and the health emergencies that society is facing today [3,4]. Thus, the integration of sustainability principles in education curricula is an important endeavor for higher education [5].

This endeavor requires a Whole Systems Approach, starting by creating a shared vision of sustainability for all HE stakeholders. It continues by establishing the curricula, pedagogies, educator training programs, and learning environments that will enable learners to develop the competences for such a vision to realize, while making interconnections between all aspects of the organizational and operational structure of the institution [6]. An example of a systemic vision for sustainability in HE based on the SDGs would include establishing the following sustainability attributes [2,7]:

- achieving the Safe Operating Space by respecting planetary boundaries such as fresh-water use, climate change and biogeochemical flows (SOS),
- achieving the Just Operating Place by establishing the required social foundation for all people to prosper (JOS),
- enabling Resilient Sustainable Behaviors that make learners critical thinkers and adept decision-makers in complexity and uncertainty (RSB),
- engaging with Alternative Economic Models (AEM) that respect planetary and human Health and Wellbeing (HW),
- practicing Transparent Governance (TG),
- enhancing inter and trans-disciplinary Collaboration (COL) and promoting Diversity and Inclusion (DI).

The ongoing discourse about sustainability and the realization of the SDGs makes research into sustainability competences all the more pertinent. Competences represent an integrated set of knowledge, skills, attitudes, and values that people bring into play in different contexts (society, education, work, and family) to address situations involving complex challenges [8–10]. Moreover, competences refer to both the performance ability to deliver a task and the willingness to engage in the task, and therefore have direct links with motivation, worldview, and values [11]. Over the past few years, sustainability education programs, reflecting the interdisciplinary and collaborative nature of the new science of sustainability, have made significant progress in conceptualizing key competencies for sustainable development [12,13]. Foresighted or anticipatory thinking, systems thinking, interdisciplinary work, and participation are examples of some of the competencies targeted by higher education sustainability programs [3,14,15].

The integration of competences in HE curricula, in turn, has implications for the educational process as the curriculum content, pedagogy, and assessment should ensure the defined educational outcomes are met. A curriculum for sustainability should provide space for learners to explore, analyze, and engage with the world around them holistically, and to develop the competences that will enable them tackle its complexities and realize the vision of the 2030 agenda [16]. Research relating sustainability competences to appropriate pedagogies for their development concludes that among the most effective approaches are problem- and project-oriented learning [17–19], as they offer opportunities for active, collaborative, and action-oriented learning and foster research skills [20].

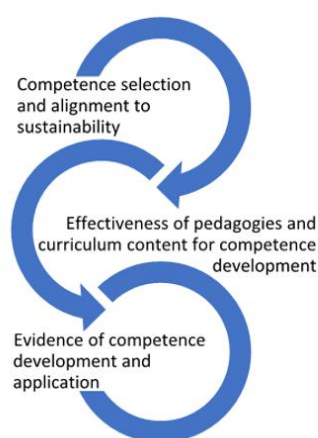
Authentic assessment is framed in the form of learning experiences that progress from simple to complex and ultimately prepare students to apply their competences to real-world situations with teachers acting as facilitators [21]. Taking into account the aspirational component of sustainability competences, relating them to the willingness to act and showcase application of the capability embedded in knowledge and skills [22], assessments need to be designed in ways to enable students to demonstrate the intended competences.

The consistency between competences, defined learning outcomes, and ways to teach and assess them are significant indicators that the curriculum engages students in authentic learning about sustainability [23,24]. While progress has been clearly made in incorporating sustainability in university educational offerings, there is little available research on the extent to which HE institutions are effective in equipping students with sustainability competences [25]. In fact, there is a clear need for the development and application of evaluation tools that can support universities to monitor and manage their contribution to sustainability. The aim of this study is to present the development and application of an assessment framework for developing and evaluating sustainability competence in university students. The framework enables translation of existing programs' learning outcomes into competences for sustainability, considers and evaluates the capacity of existing assessments of learning to enable students to apply their competences, and provides evidence on the effectiveness of HE programs.

## 2. Materials and Methods

### 2.1. Assessment Framework Methodology

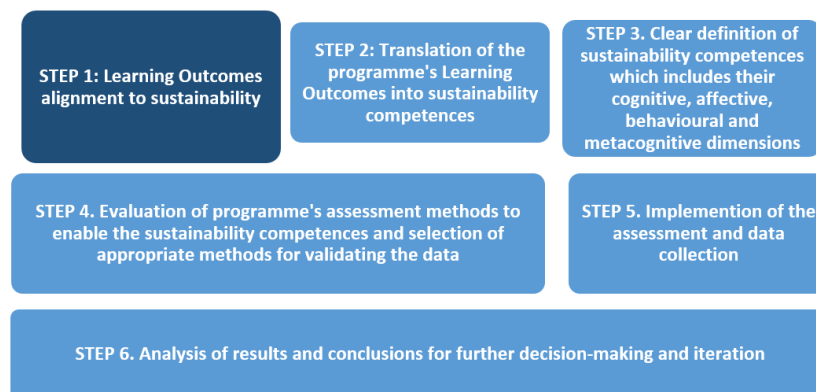
The assessment framework evaluates a program's alignment of learning outcomes (LOs) to sustainability, the capacity of existing and new assessments to measure them, and provides evidence of competence development in learners through a collection of tools and approaches in a six step methodology. It requires a sustainability vision to be developed by the program of study, clear learning outcomes that describe the competences the students will have developed after its completion and assessments, and pedagogies designed to allow students to mobilize and apply these competences to respond to a number of challenges in a way that students develop the associated intended competences. The interconnected nature of competence selection, effectiveness of pedagogies, curriculum content, and assessment for the development of competence in learners forms the basis of the framework that enables HE institutions to evaluate the development of their learners' sustainability competences (Figure 1).



**Figure 1.** Conceptual framework for the sustainability competence assessment framework (authors' own work).

The assessment framework comprises six steps (Figure 2). To begin the assessment (step 1), teaching staff and program coordinators are encouraged to assess the alignment of their program's LOs to their sustainability vision. This can be done by comparing their learning outcomes to their stated vision and identifying gaps to address or comparing them, in absence of a stated vision, to the sustainability attributes of the SDGs guided vision mentioned in the introduction (SOS, JOS, AEM, RSB, COL, TG, DI, and HW). The tool for this, which is based on a set of word codes for each sustainability attribute that the LOs are compared against, provides insight on the areas of sustainability that are included or excluded in the LOs and helps university program developers to understand what their educational offer supports in terms of the SDGs and what gaps they should address in terms of holistic representation of sustainability [7].

The next step includes the translation of the aligned LOs into a set of competences (step 2). Consultation with the academic staff, students participating in the program, and other relevant stakeholders, such as alumni and professional accreditation bodies, can further facilitate this step. The process of translation examines the following curricular concepts to ensure constructive alignment between LOs, content, pedagogy, and assessment: (1) 'what is the student expected to know and do for sustainability?'; (2) 'what is to be taught and learnt for sustainability?'; (3) 'how is it to be taught and learnt?'; and (4) 'how is it to be assessed?' [26].



**Figure 2.** Representation of the six steps included in the sustainability competence assessment framework (authors' own work).

Then (step 3), competences are defined using clear statements on what the students need to master and their cognitive, affective, behavioral and metacognitive dimensions are described [27]. Performance indicators for each dimension state what the learner is expected to know and be able to do and should be appropriate for the level of study they target. The indicators of competence performance reflect learners' cognitive abilities such as knowledge [28], understanding [29], and applied skills [30,31]. In addition, indicators include socio-emotional skills, which are attitudinal and behavioral [23,30,32], and metacognitive abilities related with the evaluation of intentions and actions [33,34].

The assessment framework then (step 4) requires the evaluation of the course's own assessment methods to establish how well these methods assess students' competence development and, if necessary, the development of new ones. These assessments can be formative, used during the course to motivate learning and/or summative at course completion to evaluate learning. To facilitate this evaluation, a typology of indicative assessment methods is provided for the assessment of sustainability competences sourced from the literature in Table 1; instead, this reflects current understanding of important competences for sustainability and is intended to give an overview of the domain to HE practitioners but is not an exhaustive list neither of competences nor of assessment tools. These can assist program coordinators in developing new assessment methods when existing ones are found to be inadequate, as well as incentivizing curricula that encourage competence development while giving students the opportunity to reflect on them [22].

Assessments should offer students opportunities to develop agency by engaging in authentic learning [35,36]. Research considers active learning tasks, such as case studies, complex, real-world project and problem-based tasks related to sustainability (comprising environmental, social and economic challenges) to contribute to sustainability competence development [24,37]. This is because students are enabled to act upon their knowledge, skills, and attitudes, experience them, and be in the position not only to understand what they entail but to use them as well [21,23,28]. Furthermore, these tasks should assist not only the development of students' content knowledge but also the further transformation of their abilities through cognitive dissonance [38], collaboration [39], and active contribution [21,40].

The students faced with complex tasks will utilize their previous knowledge and skills and act from certain worldview, value-orientation, and perspective as starting point [31,41]. As they uncover more information on the task, link different concepts, engage in discussions with others, test their own ideas and compare them with others, they stretch their zone of proximal development [42]. This mobilizes them to develop a plan of action to control their learning and apply it in the real world, thus mastering it as a consequence [43–45]. When assessments have been designed to require learners to demonstrate how they have developed the program's competences and how they can apply them to respond to a number of challenges, the formal assessment process can begin.

**Table 1.** Sustainability competences and some appropriate tools for their assessment based on literature review [2,3,8,15,46].

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>● <b>Competence: Systems Thinking</b></p> <p>Assessment tools: Concept maps (conceptual diagrams that represent the relationships between concepts) [47], computer simulations of complex systems and qualitative modelling of systems (elements, interactions and impact analysis) [48,49], self-assessment surveys [50] and problem scenarios where students are asked to bridge the gap between the current state and a goal or desired state [51].</p>                                                              |
| <p>● <b>Competence: Future thinking</b></p> <p>Assessment tools: Scenario construction (defining goals, objectives, processes, exploring what will happen, can happen or should happen), visioning exercises (exploring various desirable futures), foresight (identification of emerging trends and uncertainties), back-casting (exploring the feasibility of scenarios and visions) [8,52–54].</p>                                                                                                                      |
| <p>● <b>Competence: Collaboration</b></p> <p>Assessment tools: Collaborative problem-solving activities, such as projects and case studies (working together to form aim, objectives, goals and outcomes for a specific problem or case), transdisciplinary work (working with academic and community stakeholders to define and address a problem) [8,37]; collaborative computer assessments and games [55,56], focus groups and interviews [57], self and peer assessments [58,59].</p>                                 |
| <p>● <b>Competence: Strategic thinking</b></p> <p>Assessment tools: Case study analysis, stakeholder analysis (who has power and interest over a plan), SWOT analysis (strengths, weaknesses, opportunities and threats of an action), devising strategies (identify short and long term goals and objectives and map actions), force field analysis (explore drivers and barriers to change and plan action accordingly) [60–62].</p>                                                                                     |
| <p>● <b>Competence: Normative thinking</b></p> <p>Assessment tools: Argument mapping (diagrammatic analysis of arguments, reasoning and evidence), six hats thinking (seeing a problem through different perspectives), debates (supporting opposing views on a statement), normative scenarios (how things should be) [53,63–65].</p>                                                                                                                                                                                     |
| <p>● <b>Competence: Effective communication (oral and written)</b></p> <p>Assessment tools: Oral presentation [66], written reports [67], essays, portfolios [68], lab or course diaries, role play [69]</p>                                                                                                                                                                                                                                                                                                               |
| <p>● <b>Competence: Modelling sustainable behavior</b></p> <p>Assessment tools: Student Conference (students organise, submit abstracts, papers, peer-review, hold roundtable discussions and present) [70], reasoning exercises, observations of students performance and completion of assessment rubrics [59], SuliTest (survey that measures sustainability knowledge and skills) [71], Sustainability values test [72].</p>                                                                                           |
| <p>● <b>Competence: Critical thinking</b></p> <p>Assessment tools: Argument mapping, debates, critical essay analysis [73,74], critical writing [63,65]; critical thinking questionnaires, reflective writing [75].</p>                                                                                                                                                                                                                                                                                                    |
| <p>● <b>Competence: Self-awareness and self-regulation</b></p> <p>Assessment tools: Self-assessments and focus groups [59], computer based self-evaluations [76], the 4Cs framework (conviction, convincing, compelling, conforming) [77], reflective writing [75], rubrics.</p>                                                                                                                                                                                                                                           |
| <p>● <b>Competence: Emotional intelligence and management</b></p> <p>Assessment tools: Six hats thinking, Emotional intelligence appraisal (a performance-based assessment) [78], MSCEIT test (picture-based test) [79].</p>                                                                                                                                                                                                                                                                                               |
| <p>● <b>Competence: Ability to use media</b> (media literacy is about the use, critical understanding and communication of information through media)</p> <p>Assessment tools: presentations, videos [80], podcasts [81], blogs, social media posts [82], self-assessment and independent assessment rubrics serve to assess the use of media, evaluating message, content, target audience, motives in a media piece as essay [83], interaction/collaboration/communication analytics through digital platforms [84].</p> |
| <p>● <b>Competence: Decision making</b></p> <p>Assessment tools: Complex problem scenarios where the student is physically or through computer simulations asked to solve [85], socio-ecological dilemmas [86], serious games [87] and social simulations [88].</p>                                                                                                                                                                                                                                                        |
| <p>● <b>Competence: Sustainability literacy</b></p> <p>Assessment tools: Tests, exams and essays/reports (for checking knowledge and understanding, written communication, analysis and synthesis) [59]; New Environmental Paradigm scale (survey that measures pro-ecological worldview) [89], SuliTest [71], multiple choice test (systems, action and effectiveness knowledge) [90].</p>                                                                                                                                |

The formal assessment process (step 5) aims to both evaluate student performance or progress and provide evidence on the efficacy of the learning and teaching process. The formal student assessment starts with the application of the assessment methods found appropriate, or were developed from scratch in the previous step by the program leaders and the collection of their data. Ideally, assessments in conjunction with generating data of student performance should help students monitor their own progress and reflect on their learning experience while also providing the opportunity for staff to reflect on the

students' level of achievement and revise teaching methods accordingly. The process can be facilitated by the development and application of rubrics that consist of fixed scales with points corresponding to the performance indicators descriptions of the competences assessed, making it easier to measure and communicate students' performance of these [91]. These indicators consist of levels, such as below basic, basic, intermediate, advanced, and expert and assist the educators to score the ability of the students to perform the task described [92]. The rubrics can be easily adapted for student reflection on their developed knowledge, skills, and attitudes. Apart from educator and student rubrics, assessment data can be collected from peer-assessment surveys, problem-solving tasks, observation of student work, interviews, and focus groups with the students, project-work, and other tools (Table 1). Data from these assessment tools in combination with the data from the formal assessment methods can be used in order to triangulate the assessment results (using two or more assessment measures to deduce the performance of a student or a team) for validity reasons [93].

Once the competence assessment is concluded, the contribution of a program to developing sustainability competences in its learners can be identified (step 6). This can be done by analyzing the data collected and making informed decisions about changes in the teaching and learning methods used, enabling students to be actively involved in teaching and assessment, and reflecting on lessons learnt and how things can be done differently in the future. The tool was applied in the context of a well-established MSc program in the environmental field at UK University, and findings are discussed in the context of additional data collected, as well as an evaluation of the tool through direct input from students via self-reflective questionnaires.

## 2.2. Assessment Framework Application in a University Case Study

The Master's program in "Environmental Technology" at Imperial College London has a general orientation towards sustainability as is stated in its mission and practices (curriculum development, teaching and learning methodologies) that allows for this kind of experimentation [94,95].

The course aims to equip students with the necessary knowledge and skills to pursue a career in the environmental sector. It also aims to develop in learners the ability to solve sustainability problems through an interdisciplinary and systems approach, using critical enquiry, developing their ability to communicate and manage self and resources independently and as part of a group, and applying analytical, research, and ICT tools appropriately [94]. The course spans three terms, the core course term, the option term, and the independent research term. The pedagogical approaches used in teaching and learning include both teacher-centered techniques (lectures and demonstrations aided by audio-visual tools) and learner-centered strategies (discussions, collaborative projects, independent research essays, small group seminars, policy seminars, practical exercises, case studies, and computer-based activities). The students are mostly assessed on the knowledge they gain through exams and on the skills they develop through project work reports, collaborative and independent essay writing, and practical exercises results/reporting.

The assessment framework case study was implemented during the academic year, 2018–2019. For this study, the focus was on the option term as it touches on all the intended sustainability LOs and students of the Water Management, Pollution Management, and Environmental Analysis and Assessment options of the program were recruited. Those students were selected as they constitute three different and self-contained subgroups showing some variation in intended competences development, learning methods used, and assessments applied while constituting parts of the same course, but share important similarities in their knowledge and skills orientation as they are all part of the Natural Sciences option. The gender, student status, and ethnicity data for the 52 students recruited are summarized per group in Table 2.

**Table 2.** Gender, student status and ethnicity data for the sample of students recruited from the Water Management, Pollution Management and Environmental Analysis and Assessment options for the purpose of this study.

| Natural Sciences Option Data (N = 52)                |                                           |                                                                              |
|------------------------------------------------------|-------------------------------------------|------------------------------------------------------------------------------|
| Gender                                               | Student Status                            | Ethnicity                                                                    |
| Water Management Option (WM) (N = 19)                |                                           |                                                                              |
| 60% Women, 40% Men                                   | 20% Home/UK, 80% Overseas                 | 65% Chinese, 15% White, 15% Asian, 5% Black                                  |
| Pollution Management Option (PM) (N = 16)            |                                           |                                                                              |
| 81.25% Women, 18.75% Men                             | 18.75% Home/UK, 12.5% EU, 68.75% Overseas | 56.25% Chinese, 31.15% White, 6.25% Black Caribbean, 6.25% prefer not to say |
| Environmental Analysis and Assessment (EAA) (N = 17) |                                           |                                                                              |
| 64.3% Women, 35.7% Men                               | 7.1% Home/UK, 7.1% EU, 85.8% Overseas     | 78.6% Chinese, 14.3% Asian, 7.1% White                                       |

The application of the six steps of the assessment framework in the Master's program in Environmental Technology is described below.

The Master's program had already established learning outcomes in its curriculum (Table 3) but did not include a sustainability vision, and thus the LOs were evaluated on their alignment to the sustainability attributes using the respective tool as per step 1 of the assessment framework methodology. The LOs alignment to sustainability attributes was high in terms of the SOS, AEM, RSB, COL, and TG [7]. However, there were areas of low coverage for JOS, HW, and DI, which are the social and institutional aspects of sustainability. These were brought to the attention of the academic staff and program director for consideration in the upcoming curriculum review.

**Table 3.** MSc Environmental Technology Learning Outcomes (Academic year 2018–2019) and translated competences.

| MSc Program LOs 2018–2019                                                                                                                                               | Translated Competences                                                              |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| 1. Use a systems approach to understanding the present and past interactions between the processes and the perturbations of these systems by human influences           | Systems thinking and dealing with complexity                                        |
| 2. Be skilled in interdisciplinary analysis, assessment and solution of sustainability problems anticipating future implications and managing uncertainty               | Future thinking and dealing with uncertainty                                        |
| 3. Be able to communicate and collaborate with specialist experts across a range of disciplines and various stakeholders                                                | Collaboration                                                                       |
| 4. Develop knowledge and understanding of environmental science, technology and policy concepts and principles                                                          | Environmental Science, Technology and Policy literacy (knowledge and understanding) |
| 5. Integrate and evaluate information from various sources, apply professional judgement, reflection and balance costs and benefits                                     | Critical thinking, reasoning and reflection                                         |
| 6. Be able to apply natural and social science research methodologies, techniques and tools for experimentation, data collection and analysis                           | Research competence                                                                 |
| 7. Plan, conduct and write-up a program of original research                                                                                                            |                                                                                     |
| 8. Analyse and assess the natural/ social science literature effectively                                                                                                |                                                                                     |
| 9. Communicate research, strategies and policy implications effectively through presentations and professional reports use of Information and Communications Technology | Effective communication                                                             |
| 10. Formulate strategy to address sustainability problem (prevention, mitigation, remediation)                                                                          | Strategic thinking                                                                  |
| 11. Assess different options and weigh trade-offs to reach decision                                                                                                     | Decision making                                                                     |
| 12. Learn independently with open-mindedness and critical enquiry                                                                                                       | Self-regulation, self-awareness and management skills                               |
| 13. Learn from the shared experiences with others                                                                                                                       |                                                                                     |
| 14. Develop self-confidence, efficiency and resilience                                                                                                                  |                                                                                     |

Next, the translation of LOs into competences (step 2) was performed in consultation with the program director, teaching staff (Lecturers and Teaching Fellows), program developers (Senior Strategic Teaching Fellow), students, and alumni. The competences that the program aims to develop and assess in the students of the options recruited can be found in Table 3.

To evaluate competence performance in those students, competence statements and indicators covering the cognitive, affective, and behavioral aspects of competence were developed by applying the procedure outlined in the methodology section (step 3) and can be found in Supplementary Material. It must be noted that Collaboration and Effective Communication competences were grouped together as it made sense to evaluate them at the same time because of the specific learning activities that students participated in that required effective communication to achieve working as a group and/or collaborate as a group to achieve effective written communication through group reports. Performance levels for each indicator of competence were structured in consultation with staff, with five levels of performance ranging from below basic, basic, and intermediate, to advanced and expert. The accepted level of performance is basic, which corresponds to 50–59% performance score, deemed as satisfactory for the MSc student to pass. The below basic level corresponds to poor/limited ability to perform the task considering the MSc level (<50%). Intermediate ability shows good (above satisfactory) performance in the task with occasional shortcomings (60–69%), advanced level shows very good performance showing novel insights into the problem (70–79%) and expert performance shows high degree creativity and innovative thinking ( $\geq 80\%$ ). The target threshold for the performance of the students of this program in the selected competences was set at Intermediate (60–69%).

These performance levels were further divided into qualitative categories. The 50–54% refers to “satisfactory, with a reasonable grasp of the relevant concepts and facts, but little evidence of the ability to synthesize and or evaluate, or with significant lapses”. The 55–59% refers to “satisfactory, with a good grasp of the relevant concepts and facts, but little evidence of the ability to both synthesize and evaluate, or with marked lapses”. The 60–64% refers to “a good grasp of the subject and some evidence of ability to synthesize and criticize”. and the 65–69% to “A very good grasp of the subject and evidence of ability to synthesize and criticize including use of supplementary reading, but falling short of excellence in one or more of these aspects”. The qualitative description for 70–79% refers to “Showing a thorough grasp of the subject, and ability to synthesize and criticize, with critical use of supplementary reading, occasionally falling below a general level of excellence (i.e., original insights and innovative thinking)”. The 80–89% refers to “excellent throughout, demonstrating a detailed knowledge and systematic understanding of key aspects of the subject, with strong evidence of independent thinking and original insights to the subject”. Finally, the 90–100% refers to “outstanding—making an original contribution, by questioning or challenging prevailing paradigms, offering new insights that are informed by critical evaluation of current research/practice, clearly demonstrating innovative/creative thinking”.

As per step 4, the formal assessment methods used in the options where assessed. They included oral presentations (formative and summative) as well as written reports of student work (summative), either individual or group-based with some variation across the three groups. In addition, exams played an important role in assessing knowledge and understanding of scientific concepts, environmental management, and assessment practices. These assessment methods offered opportunities for data collection regarding the selected competences (Table 3) according to the typology presented in Table 1. The oral presentations and written reports aimed to assess effective communication. The project reports required the students to develop system models and thus use systems thinking; short and long-term strategies to address problems and thus strategic thinking; and cope with future uncertainties related to environmental, political, and financial changes, and thus future thinking. They also had to consider the values and needs of stakeholders, manage trade-offs and make decisions, thus use decision making and collect, analyze and

synthesize appropriate data to support their decisions and conclusions, thereby using their research and critical thinking skills. However, collaboration, self-regulation, team monitoring, and leadership were only assessed through informal discussions between the educators and the students during meetings regarding project progression.

Considering the above, the formal assessments were used to capture competence development in students. To triangulate the results, they were supplemented by educator assessment rubrics and student self-assessment surveys (step 5) (Supplementary Material). In addition, this was performed to provide educators with the opportunity to assess and reflect on students' individual and group work and to give voice to the students regarding their assessment, as traditionally, only the educators evaluated student learning for this course module. The assessment tools that were used as part of the assessment framework to assess the option competences in students can be found in Table 4.

**Table 4.** Description of option modules, assessment methods used and competences assessed in the MSc Environmental Technology.

| Option (Module)                                                     | Assessment Tools Used                                                                       | Competences Assessed                                                                                                                                                                                                                  |
|---------------------------------------------------------------------|---------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Water Management</b>                                             | <b>Exam and course work</b>                                                                 | Knowledge and understanding of water systems and water management                                                                                                                                                                     |
| Anglian Water Project (AWP)<br>(work in small groups *)             | Group report and course work                                                                | Systems thinking and dealing with complexity<br>Future thinking and dealing with uncertainty<br>Critical thinking, reasoning and reflection<br>Research competence<br>Strategic thinking<br>Collaboration and effective communication |
| Hounslow Heath Project (HHP)<br>(work in two big groups *)          | Group presentation and Individual report                                                    | Decision-making<br>Self-regulation, self-awareness and management skills                                                                                                                                                              |
| <b>Environmental Assessment and Analysis</b>                        | <b>Exam and course work</b>                                                                 | Knowledge and understanding of resource depletion and contamination assessment and management                                                                                                                                         |
| Hounslow Heath Project (HHP)<br>(work in two big groups *)          | Group presentation and Individual report                                                    | Systems thinking and dealing with complexity<br>Future thinking and dealing with uncertainty<br>Critical thinking, reasoning and reflection<br>Research competence<br>Strategic thinking<br>Collaboration and effective communication |
| Waste Management Project (WMP)<br>(Phase 1: work in small groups *) | Phase 1: Group report and individual presentation                                           | Decision-making<br>Self-regulation, self-awareness and management skills                                                                                                                                                              |
| (Phase 2: work in two big groups *)                                 | Phase 2: Individual report and group presentation                                           |                                                                                                                                                                                                                                       |
| <b>Pollution Management</b>                                         | <b>Exam and course work</b>                                                                 | Knowledge and understanding of pollution problems and pollution assessment and management                                                                                                                                             |
| Waste Management Project (WMP)<br>(Phase 1: work in small groups *) | Phase 1: Group report and individual presentation<br>(assessed all competences in column 3) | Systems thinking and dealing with complexity<br>Future thinking and dealing with uncertainty<br>Critical thinking, reasoning and reflection<br>Research competence<br>Strategic thinking<br>Collaboration and effective communication |
| (Phase 2: work in two big groups *)                                 | Phase 2: Individual report and group presentation                                           | Decision-making<br>Self-regulation, self-awareness and management skills                                                                                                                                                              |
| Pollution management Case Studies                                   | Group presentation and Individual report                                                    |                                                                                                                                                                                                                                       |

\* The students who participated in the AWP worked consistently in teams of 4 to 5 people throughout the duration of the project. The students who worked in the WMP started in groups of 3 people and half-way through the project merged into two big groups consisting of 15 students. Lastly, HHP students worked in two big groups throughout the project.

### 3. Results

Both the educator rubrics and the self-assessment survey (Supplementary Material) consisted of statements, corresponding to the competences assessed. The rubrics were given to the educators to assess student reports and the surveys were given to the students

to complete at the end of their project work. Twelve (12) educator assessment rubrics and 81 student self-assessment questionnaires were collected in total. The self-assessment survey was administered to the AWP, WMP, and HHP students and, due to access limitations, was not given to the PM case studies students.

The results of the formal assessment for the three groups of students are summarized in Table 5, showing the average marks for the students of the Water Management, Pollution Management, and Environmental Assessment and Analysis collected through the various formal assessment methods used for the needs of the program per option.

**Table 5.** Average marks for each option module per assessment method.

| Option (Module)                                                            | Assessment                          | Competences Assessed                                                                                                                                                                                                  | Average Mark |
|----------------------------------------------------------------------------|-------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|
| <b>Water Management (N = 19)</b>                                           | <b>Exam and Course Work (Total)</b> | <b>All the Below</b>                                                                                                                                                                                                  | <b>69</b>    |
| Water systems and Water management                                         | Exam                                | Knowledge and understanding                                                                                                                                                                                           | 66           |
| Anglian Water Project (AWP) coursework (work in small groups *)            | Group report                        | Systems thinking/Complexity<br>Future thinking/Uncertainty<br>Critical thinking/Reasoning/Reflection<br>Research competence<br>Strategic thinking<br>Decision-making                                                  | 74           |
|                                                                            | Individual presentation             | Collaboration & Effective communication<br>Self-regulation/self-awareness/management                                                                                                                                  | 72           |
| <b>Total for AWP coursework</b>                                            |                                     |                                                                                                                                                                                                                       | <b>74</b>    |
| Hounslow Heath Project (HHP) coursework (work in two big groups *)         | Individual report                   | Systems thinking/Complexity<br><br>Future thinking/Uncertainty<br>Critical thinking/Reasoning/Reflection<br>Research competence<br>Strategic thinking<br>Decision-making<br>Collaboration and Effective communication | 72           |
| <b>Environmental Assessment and Analysis (N = 17)</b>                      | <b>Exam and course work</b>         | <b>All the below</b>                                                                                                                                                                                                  | <b>67</b>    |
| Resource depletion and contamination assessment and management             | Exam                                | Knowledge and understanding                                                                                                                                                                                           | 64           |
| Hounslow Heath Project (HHP) coursework (work in two big groups )          | Individual report                   | Systems thinking/Complexity<br><br>Future thinking/Uncertainty<br>Critical thinking/Reasoning/Reflection<br>Research competence<br>Strategic thinking<br>Decision-making<br>Collaboration and Effective communication | 73           |
|                                                                            |                                     |                                                                                                                                                                                                                       |              |
| Waste Management Project (WMP) coursework (Phase 1: work in small groups ) | Phase 1: Group report               | Systems thinking/Complexity<br><br>Future thinking/Uncertainty<br>Critical thinking/Reasoning/Reflection<br>Research competence<br>Strategic thinking<br>Decision-making                                              | 69           |
|                                                                            | Individual presentation             | Collaboration & Effective communication<br>Self-regulation/self-awareness/management                                                                                                                                  | 71           |

Table 5. Cont.

| Option (Module)                                                              | Assessment                          | Competences Assessed                                                                                                                                                                                                                                         | Average Mark |
|------------------------------------------------------------------------------|-------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|
| <b>Water Management (N = 19)</b>                                             | <b>Exam and Course Work (Total)</b> | <b>All the Below</b>                                                                                                                                                                                                                                         | <b>69</b>    |
| Waste Management Project (WMP) coursework (Phase 2: work in two big groups ) | Phase 2: Individual report          | Systems thinking/Complexity<br>Future thinking/Uncertainty<br>Critical thinking/Reasoning/reflection<br>Research competence<br>Strategic thinking<br>Decision-making<br>Collaboration and Effective communication                                            | 65           |
| <b>Total for WMP coursework</b>                                              |                                     |                                                                                                                                                                                                                                                              | <b>68</b>    |
| <b>Pollution Management (N = 16)</b>                                         | <b>Exam and course work</b>         | <b>All the below</b>                                                                                                                                                                                                                                         | <b>67</b>    |
| Pollution problems and pollution assessment and management                   | Exam                                | Knowledge and understanding                                                                                                                                                                                                                                  | <b>65</b>    |
| Waste Management Project (WMP) coursework (Phase 1: work in small groups )   | Phase 1: Group report               | Systems thinking/Complexity<br>Future thinking/Uncertainty<br>Critical thinking/Reasoning/Reflection<br>Research competence<br>Strategic thinking<br>Decision-making<br>Collaboration & Effective communication<br>Self-regulation/self-awareness/management | 69           |
|                                                                              | <i>Individual presentation</i>      |                                                                                                                                                                                                                                                              | 72           |
| Waste Management Project (WMP) coursework (Phase 2: work in two big groups ) | Phase 2: Individual report          | Systems thinking/Complexity<br>Future thinking/Uncertainty<br>Critical thinking/Reasoning/Reflection<br>Research competence<br>Strategic thinking<br>Decision-making<br>Collaboration and Effective communication                                            | 67           |
| <b>Total for WMP coursework</b>                                              |                                     |                                                                                                                                                                                                                                                              | <b>69</b>    |
| Pollution management Case Studies (PMCS) coursework                          | Group report                        | Systems thinking/Complexity<br>Future thinking/Uncertainty<br>Critical thinking/Reasoning/Reflection<br>Research competence<br>Strategic thinking<br>Decision-making<br>Collaboration & Effective communication<br>Self-regulation/self-awareness/management | 69           |
|                                                                              | <i>Individual presentation</i>      |                                                                                                                                                                                                                                                              | 69           |
| <b>Total for PMCS coursework</b>                                             |                                     |                                                                                                                                                                                                                                                              | <b>69</b>    |

In terms of knowledge and understanding, the students of the WM option received 66 (B merit upper), the students of EAA options received 64 (B merit lower), and the students of the PM option received 65 (B merit upper).

In terms of the other competences evaluated, the students of the WM option received marks between 72 and 74, which represent the A distinction category. The students of the EAA option received marks between 65 (B merit upper) and 73 (A distinction) in terms of systems, future, critical and strategic thinking, decision-making, and research skills for both the individual and group coursework, and 71 (A distinction) for collaboration,

effective communication, and self-regulation and in their small group work. The students of the PM option received marks between 67 and 69 (B merit upper) for the competences systems, future, critical and strategic thinking, decision-making and research skills, and for collaboration, effective communication, and self-regulation received marks between 69 (B merit upper) and 72 (A distinction). In all cases, group competences received higher average scores than individual ones.

The educator assessment rubrics results showed, for the students of the WM option, intermediate (60–69%) to advanced (70–79%) levels in the competences systems, future, strategic, decision making, critical thinking and research skills, and an intermediate level for collaboration, effective communication, and self-regulation. For the students of the EAA option, the results showed an intermediate level for all competences, apart from collaboration, effective communication, and self-regulation for which the results showed an intermediate to advanced level. For the students of the PM option, the results showed intermediate level for all competences. The rubrics mainly assisted the educators in assessing more easily and clearly the level of student competence, as the formal assessment criteria were only focused on assessing the coursework produced (e.g., reports and presentations), and giving rich and targeted feedback for each competence examined in the feedback report given to the students. The students, on the other hand, received feedback on their individual as well as group work. An example of the feedback given to a group of students of the WM option based on the formal assessment criteria and the educator rubrics is provided in Supplementary Material.

Students were given a self-assessment survey to reflect on their developed competences through teamwork. The same survey allowed educators to gain understanding about the performance of the students as a team and thus assess their collaboration competence. The self-assessment results per project are shown in Table 6a–c. Notably, WM students self-assessed their competences higher than PM and EAA students. Systems thinking for WM and PM and decision making for EAA students were the strongest competences, whereas research competence for WM, collaboration for PM, and future thinking for EAA were the weakest competences reported by the students.

Overall, the lowest scored competences future thinking and dealing with uncertainty and research competence for EAA option students and collaboration and critical thinking for PM students seemed to belong to the 50–59% “basic qualitative category” which is not aligned with the expected level of student competence at the Master’s level—which is Intermediate (60–69%)—and should be given more attention by the program coordinators in a curriculum review.

**Table 6.** (a) Descriptive Statistics of the self-assessment survey results of the WM students. (b) Descriptive Statistics of the self-assessment survey results of the EAA students. (c) Descriptive Statistics of the self-assessment survey results of the PM students.

| (a)                      |    |         |         |      |                |                   |
|--------------------------|----|---------|---------|------|----------------|-------------------|
| Competence               | N  | Minimum | Maximum | Mean | Std. Deviation | Normalised Scores |
| Systems thinking and ... | 19 | 3.00    | 5.00    | 4.16 | 0.602          | 78.95             |
| Future thinking and ...  | 19 | 2.00    | 5.00    | 3.68 | 0.885          | 67.11             |
| Decision making          | 19 | 2.00    | 5.00    | 3.84 | 0.602          | 71.05             |
| Critical thinking        | 19 | 3.00    | 5.00    | 3.68 | 0.582          | 67.11             |
| Collaboration            | 19 | 3.00    | 5.00    | 3.84 | 0.501          | 71.05             |
| Research competence      | 19 | 1.00    | 5.00    | 3.63 | 1.012          | 65.79             |
| Self-regulation, ...     | 19 | 2.50    | 5.00    | 3.76 | 0.586          | 69.08             |
| Strategic thinking       | 19 | 3.00    | 5.00    | 4.00 | 0.667          | 75.00             |
| Valid N (listwise)       | 19 |         |         |      | Average        | 70.64             |

Table 6. Cont.

| (b)                     |    |         |         |      |                |                   |
|-------------------------|----|---------|---------|------|----------------|-------------------|
| Competence              | N  | Minimum | Maximum | Mean | Std. Deviation | Normalised Scores |
| Systems thinking and... | 32 | 1.00    | 5.00    | 3.41 | 1.012          | 60.16             |
| Future thinking and ... | 32 | 1.00    | 5.00    | 3.09 | 1.174          | 52.35             |
| Decision making         | 32 | 1.00    | 5.00    | 3.78 | 0.870          | 69.53             |
| Critical thinking, ...  | 32 | 1.00    | 5.00    | 3.56 | 0.948          | 64.06             |
| Collaboration and..     | 32 | 1.00    | 5.00    | 3.41 | 1.043          | 60.16             |
| Research competence     | 32 | 2.00    | 5.00    | 3.14 | 0.961          | 53.52             |
| Self-regulation, ...    | 32 | 1.00    | 5.00    | 3.69 | 0.896          | 67.19             |
| Strategic thinking      | 32 | 1.00    | 5.00    | 3.55 | 0.910          | 63.67             |
| Valid N (listwise)      | 32 |         |         |      | Average        | 61.33             |
| (c)                     |    |         |         |      |                |                   |
| Competence              | N  | Minimum | Maximum | Mean | Std. Deviation | Normalised Scores |
| Systems thinking        | 30 | 3.00    | 5.00    | 3.77 | 0.679          | 69.17             |
| Future thinking         | 30 | 2.00    | 5.00    | 3.43 | 0.817          | 60.83             |
| Decision making         | 30 | 2.00    | 5.00    | 3.50 | 0.777          | 62.50             |
| Critical thinking       | 30 | 2.00    | 5.00    | 3.37 | 0.669          | 59.17             |
| Collaboration           | 30 | 2.00    | 5.00    | 3.23 | 0.935          | 55.83             |
| Research competence     | 30 | 2.00    | 5.00    | 3.43 | 0.898          | 60.83             |
| Self-regulation, ...    | 30 | 2.00    | 5.00    | 3.57 | 0.774          | 64.17             |
| Strategic thinking      | 30 | 2.00    | 5.00    | 3.50 | 0.820          | 62.50             |
| Valid N (listwise)      | 30 |         |         |      | Average        | 61.88             |

When comparing student self-assessment scores with formal assessment marks, the results show that in all cases students self-assessed much lower. However, there is compatibility between the formal assessment marks and student self-assessment scores for WM and EAA students in terms of level of performance. In the first case, both assessments show A Distinction (advanced competence), and in the latter case both assessments show B Merit (intermediate competence). On the other hand, the PM students gave lower scores to themselves than the educators did (B Merit/intermediate from the students and A Distinction/advanced from the educators respectively). A reason why the students may self-assess research skills differently could be that they have been exposed to different research experiences in their undergraduate studies [96]. In addition, students may have a limited ability to self-assess their skills if not adequately trained, and this may be reflected in the overall lower scores reported [97].

The data show that for most competences, the students self-assess in the intermediate to advanced level depending on the option they attended and also received marks from B Merit (intermediate competence) to A Distinction (advanced) competence according to the formal departmental assessments and educator rubrics. When compared to the threshold set by the department (students to achieve at least intermediate level, 60–70%), the results show satisfactory attainment (step 6), with the exception already mentioned in the results from student self-assessment surveys. The competences flagged by students as their weakest should be targeted by the curriculum developers and educators in the next curriculum review. Lastly, but importantly, there will be benefits for the assessment of competences in case the Master's program management and teaching team consider inclusion and refinement of the educator rubrics and student self-assessment surveys developed for the program.

#### 4. Discussion

The tool was designed for use by higher education practitioners to evaluate student competence development. The ultimate aim is to help HE institutions evaluate their contribution to empowering graduates with sustainability competences. Its application shows that it is crucial to not only have the LOs aligned to sustainability, but to generate evidence that the translated competences are actually being developed in learners as it will help curriculum planers to develop appropriate programs. Although we provide a tool to check the alignment of LOs to sustainability attributes in the absence of a sustainability vision by the HEI, such a vision needs to be developed by the HEIs engaging all stakeholders in a participatory way, as that will guide the definition of competences to achieve it [2]. A holistic vision for the HEI will drive change in other institutional aspects that are crucial for enabling the development of sustainability competences by all. Furthermore, the tool could help HE practitioners improve/modify their assessment methods to enable active experience and appropriate assessment of the defined sustainability competences, using guidance in Table 1. This will generate evidence on the effectiveness of their teaching and learning approaches to develop those competences in students. In conclusion, assessments should be generating data and insights that help educators and students to make evidence-based decisions in terms of their teaching and learning respectively, and to identify and remediate barriers in achieving their goals.

This study addresses an important need in the academic community in relation to the multiple perspectives on sustainability on the one hand, and the diversity of existing competence frameworks and assessment tools on the other. A focus on participatory approaches in formulating competences for sustainability that fit an institution's vision, mission, aims, and needs, instead of a prescriptive approach of applying predefined competence frameworks, should be prioritized by all HE institutions. Moreover, this approach focuses on designing the selected sustainability competences into the learning and assessments activities. Thus, both learners and educators benefit from the clarity/transparency of educational aims, effectiveness of pedagogies, and accountability/ownership of outcomes. In addition, the data generated from the assessment tools enable HE practitioners to identify gaps in terms of sustainability alignment and barriers that prevent students from developing sustainability competences.

Two recent systematic literature reviews on the assessment tools for sustainability competences [59,98] place emphasis on the fact that universities put a lot of effort in compiling pedagogies that will enable sustainability competences in learners, rather than thought on which assessments are appropriate for them. The tool, placing emphasis on competences translated from LOs based on the program's mission and aim, offers a methodology for education practitioners to consider which tools to use for targeted competence assessment. Furthermore, the studies show that the most frequently used assessment tools are self-assessment questionnaires and surveys, followed by reflective writing (essays, reports, and diaries) and focus groups/interviews. The least used and maybe more refined tools are concept maps, coursework assignments, and rubrics. Therefore, a combination of the above tools is needed to capture competence development in students and application in appropriate teaching and learning activities.

The case study yields some useful suggestions to HE practitioners to assist them when applying the competence assessment tool. The program coordinators need to make sure the competences represent not only the main curricular, pedagogical, and assessment aspects collectively the educational ecosystem, but reflect an awareness of the diversity of perspectives, voices, and cultures comprising the staff and student bodies as well as relevant societal aspects, such as ones related to professional life and emergent social transitions. This can happen by setting and agreeing values to guide their participatory process of competence definition [99]. These values will clarify the sustainability vision pursued and thus frame the competences as enablers to achieve that vision, as otherwise traditional competences that promote unsustainability can be selected.

As far as the assessments methods are concerned, the education practitioners should focus on the ones that enable students actively experience the competences they are expected to develop and reflect on them. This can be done by using holistic assessments of the cognitive, affective and behavioral aspects of competence with its metacognitive aspects, which have been found effective in enabling intrinsic motivation and longer-term engagement [100]. It is also important to offer the students a variety of those assessment tools to both cater to the diversity of student learning styles and to capturing the complex aspects of the competence constructs [26]. This can be challenging for educators to achieve and thus consultations, meetings, and mentoring, as well as training sessions, would be beneficial for clarifying how to proceed with assessment.

One important decision-making point regarding the use of the tool is group work. Although students benefit from working in groups as they are challenged to develop their competences further, the size of a group can greatly influence the decision making processes performed by the group [101]. For example, the bigger the group, the less each member will be able to say. A larger group may inhibit certain individuals from contributing due to peer pressure. In addition, systems thinking is a competence that relates to systems analysis, and applying the necessary modelling and mapping of stakeholders and interactions may be more difficult in big groups as there may be many points of view, higher complexity and more conflict [101]. This means that when engaging the students in collaborative project work, there should be a careful selection of the size of the group and of the roles the students will play within the group. This may be correlated with their educational and professional background and personality.

While the tool presented here focuses on competences for evaluating a program's contribution to sustainability, it should be noted that competence-based assessments have also been the subject of criticism. This is attributable to the complexity of assessing poorly understood concepts, resulting in the potential to narrow the curriculum because of the increased focus on what is assessed at the expense of non-tested skills, which receive decreased attention. This entails the danger of overlooking important aspects of the student's personality as there may not be appropriate assessment methods to capture them and the caveat that using performance levels can negatively label teachers and students, thus influencing their attitudes [102]. Competence assessments alone cannot benefit educators and students if it not coupled with systemic interventions such as teacher training sessions, involving time and cost requirements for developing relevant assessment material that is sensitive to class or cohort size and norms and behaviors that create resistance to change.

Despite these reservations, competence-based assessments place the importance of assessment not only on the outcomes of learning but equally on the process and experiences that led to those outcomes [103]. Their approach further provides specific, targeted and actionable feedback to the educator and student [104]. Although competences are complex as constructs and difficult to assess, they reflect the multidimensional, integrated, and performance-based nature of assessment and in terms of their sustainability definition, they can act as indicators of closing the gap towards a sustainability vision. Lastly and importantly, competences are important for entering and progressing in a professional environment as they are sought after by employers and used in applicant screening tests [105].

Further considerations for the education practitioners viewing this case study include the fact that the assessment framework was applied in a master's course that already had strong links with sustainability. For programs that have weaker links to sustainability as well as other types of courses, for example undergraduate university courses, doctoral training programs, or school education contexts, it should be applied in future case studies to serve the needs of diverse education stakeholders. Its effectiveness as a decision-making tool can be validated in specific case studies that aim to collect and analyze data and make judgements to guide curriculum reviews. The Whole Institution Approach advocated by recent policy developments [106] emphasizes that institutional and contextual aspects play an important role in the university's contribution to sustainability. Thus, sustainability

competence development should be seen holistically i.e., from an educational, institutional and contextual perspective [21] and become aligned with whole system effectiveness in promoting competences for sustainability.

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## Article

# Modeling the Factors That Determine Sustainable Development Goal 12 in University Students

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**Abstract:** SDG12 is one of the top three Sustainable Development Goals that require more urgent action. Hence, this work aims to develop and validate a conceptual model that measures the main factors which may influence university students' sustainable consumption and to determine to what extent each one influences Sustainable Consumption Behavior. Partial Least Squares modeling is used to develop and validate the proposed model. The results indicate that Sustainable Consumption Behavior is determined by Environmental Education and Information, Green Purchase and Sustainable Consumption Habits. Identifying what motivates people to adopt this form of behavior is extremely helpful for designing relevant strategies that specifically aim to stimulate positive responses concerning the environment, economy and society.

**Keywords:** Sustainable Development Goal 12; environmental education; responsible consumption; partial least squares structural equation modeling; structural equations; consumer behavior; higher education; sustainability



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## 1. Introduction

Today's society is immersed in a consumerist environment dominated by a market full of disposable products wrapped in plastic and other polluting materials. In recent decades, a capitalist culture has been created that encourages us to buy beyond our needs, which has triggered a series of environmental problems. These problems have been analyzed for several years, and attempts have been made to find solutions to stop our planet's degradation. Notwithstanding, climate change continues to affect our lives.

Beginning in the 1970s, concern began growing about the environment, nature, and pollution and its impact on climate change. As a result, in September 2015, the United Nations Assembly approved Agenda 2030 for Sustainable Development, which establishes a transformative vision toward economic, social and environmental sustainability and is the reference guide for the international community's work. Agenda 2030 is an action plan for people and the planet. It includes 17 Sustainable Development Goals (SDGs) and 169 specific goals, developed on the basis of Millennium Development Goals (MDGs) in 2000 (United Nations, 2015; Sachs, 2012), to be achieved before 2030 that will transform our society into one of responsible living. These objectives range from social problems, such as poverty and change in education or gender equality, to technological problems. They are grouped into five action areas: people (SDGs 1–5); planet (SDGs 6, 12, 13, 14, 15); prosperity (SDGs 7–11); peace (SDG 16); partnerships (SDG 17). According to (D'Amato et al., 2019;

Hajer et al., 2015), this agenda represents a guide for action for all social actors, from governments to the private sector, and involves all stakeholders making joint efforts to effectively meet the SDGs.

This study is based on SDG12, which aims to “ensure responsible consumption and production”. This means that it intends to instill in companies the ethics of manufacturing products with minimal environmental impact and, in consumers, awareness of demanding such products and rejecting those produced with harmful materials and/or achieved through processes with a high carbon footprint or under conditions that do not respect human rights. Thus, SDG12 aims to guarantee sustainable consumption and production patterns. Its *raison d’être* is part of the need to stop the environmental degradation that has been destroying our planet in the last century.

As this sustainable objective concerns society as a whole, the measures to be taken to meet it must consider all population segments because all citizens are consumers and are, at the same time, an important part of production processes. However, consumers’ behavior could vary according to their demographic, economic and social characteristics, etc. This suggests that the design of measures must take these differences into account to guarantee their success. However, the literature review shows that there is no conceptual model to allow the factors that influence consumers’ decision-making processes and, in turn, consumers’ or households’ degree of awareness, to be measured. This means that public administrations’ efforts are limited to awareness campaigns that address all citizens in an attempt to promote waste recycling and discourage consuming products manufactured with nonrecyclable materials or involving workers’ undignified conditions, and these measures’ success has been of little relevance.

In this context, university higher education institutions can, and should, play a fundamental role in meeting SDGs on the whole, especially universities of a technological nature with SDG12 because their teaching, research and transfer activity can focus on the development of techniques, models and competences that guarantee efficient resources use and minimized waste.

In fact, as stated by Martínez-Acosta et al. (2023), SDG12 is one of the first goals whose number of mentions in publications in indexed journals have increased the most since 2018 (42.8%) in parallel to SDG7 (44.4%), SDG13 (41.5%) and SDG11 (40.5%). According to Frank et al. (2020), however, in 2020, SDG12 was one of the top three SDGs which required more urgent action in academia, administration and policy, industry and civil society.

Although SDG12 is one of the most understood and relevant ones in daily life, it ranks as one of the least popular for students in academic contexts globally and is, thus, one of the least achieved (Tedeneke, 2019; Fischer et al., 2017). Young consumers are particularly significant for researchers, policymakers and educators in the sustainable consumption field because this group’s purchasing power is rapidly growing and, in turn, increases the potential for positive sustainability impacts through their consumption choices (Fischer et al., 2017).

Young consumers, as digital natives in a globalized world, share similar conditioning across cultures, nationalities and ethnicities. However, their consumption-related behaviors are also shaped by distinct cultural, historical and individual contexts (Eagles & Demare, 1999). Childhood environments in connection to place attachment, identity and dependence, as well as cultural and environmental experiences, form the basis for environmental relations (Eagles & Demare, 1999; Chawla, 2007). Also, Yli-Panula et al. (2020) assess how teachers can determine crucial information about students’ interests and environmental values. This body of literature provides the framework for the empirical study.

Hence, the purpose of this work is to develop and validate a model that analyzes the main factors that may influence university students’ sustainable consumption. The

identification of the most relevant factors will allow teaching methodologies to be designed that educate our university students on responsible, efficient consumption and waste minimization that, in this way, will bring about a change in new generations' habits and mindsets and promote research, innovation and knowledge transfer to industries in the form of more sustainable production techniques.

In summary, the aims of this paper are to (1) determine a conceptual model to measure the main factors that may influence university students' sustainable consumption; (2) establish to what extent each one influences Sustainable Consumption Behavior; (3) validate the proposed model using Partial Least Square (PLS-SEM) (Wetzels et al., 2009).

The rest of the paper is structured as follows. Section 2 introduces the methodological framework. Section 3 presents the methodology herein followed and describes the sample used in the analysis. Section 4 provides the main results. Finally, Section 5 concludes and sets out the limitations of this paper.

## 2. Framework

People's lifestyle determines not only their relationship with the environment, but also their consumption responsibility. It is specifically influenced by the way of thinking, the social environment and daily habits. More and more people are interested in living a sustainable way of life, as evidenced during all awareness campaigns, and also in the entire supply and demand for sustainable products, such as food, clothing, electronics and any product originally made with plastics. This includes fighting planned obsolescence, which is the characteristic of products' life cycles ending when manufacturers want them to and the tendency to promote circular economy. Durability used to be an essential characteristic of any product, but companies' need to sell has led this same durability to become a disadvantage. This is because a product generates interest and sells well if it is not easily destroyed. However, the time will come when there will no longer be the need to buy that product. This is why products have begun to be manufactured in a way that renders them less durable and they have a deliberate shelf life (Leiva-Brondo et al., 2022).

Although they have made our lives easier in many ways, these are advances that consume the planet's natural resources very quickly and endanger our future development. The costs we consequently suffer are accelerated climate change, reductions in green spaces and aquatic areas, and corrosion of fertile areas. Another influence of this is the disproportionate advance of some countries compared to others, which translates into the overexploitation of less developed ones.

There are various theories, models and frameworks that help us to understand green consumer behavior by emphasizing the hierarchy of values, attitudes/norms, intentions and behaviors. These include the Theory of Planned Behavior (TPB) (Ajzen, 1985, 1991), the Theory of Reasoned Action (TRA) (Fishbein & Ajzen, 1975) and models of Ecologically Conscious Consumer Behavior (ECCB) (Ajzen, 1985). Nonetheless, they may be more useful to researchers who seek to explain green behavior by considering other factors, value-driven beliefs and norms.

As such, people's lifestyles shape their habits and behaviors in resource consumption and waste generation terms. These are considered major contributors to environmental impacts, especially greenhouse gas emissions (GG), ozone layer depletion and the production of acidifying substances (Straughan & Roberts, 1999). In this context, the challenge is to change our ways of thinking, feeling and acting to ultimately transform society as a whole. This would imply favoring sustainable development scenarios, such as shifting consumer lifestyles, reducing excessive consumption and reconsidering the value of accumulation. Re-evaluating economies based on quality of development, rather than on growth rates, would also be essential.

Empirical studies have revealed encouraging data on the existence of such behaviors. For instance, there are consumers who demand more information about sustainable products, their origin and supply chain; care about the environmental and social impacts of their consumption; respond to the influence of reference groups and purchase eco-friendly products; are even willing to pay a premium for sustainable options (Caeiro et al., 2012). Similarly, there is growing awareness of environmental protection by encompassing sustainable practices and consumption (Shao et al., 2017). All these actions indicate a shift toward sustainable lifestyles.

This is why the importance of SDG12 is prioritized in this work by providing data that reveal the importance of responsible consumption, which we attempt to promote to meet the 17 objectives established in Agenda 2030.

Although it is true that different goals and indicators in Agenda 2030 have been established that contribute to measuring the degree of their achievement, there is still a wide gap when it comes to evaluating the contribution of households or individual consumers. The closest approximation that can be found is in indicator 12.5.1: “National recycling rate, in tons of recycled material, of Goal 12.5. By 2030, significantly reducing waste generation through prevention, reduction recycling and reuse activities”. However, relevant information is missing in the calculation of this indicator and it does not take into account the different factors that may affect it. Although various actions have begun to be taken to ensure sustainable consumption, the gap is still wide, hence the purpose of this research.

In this context, this article aims to define how certain social factors contribute to sustainable consumption by generating a model that explains Sustainable Consumption Behaviors of university students in the Valencian Community, which stands out in Spain for the number of centers of university educational excellence and the number of university students. To provide a global applicable definition to the different methodologies for measuring SGD 12, various theories and acceptance models have been consulted, but we focus mainly on (Figuerola-García et al., 2018; Tabernero et al., 2015; Kowalska et al., 2021; Do Paco et al., 2019). The social factors presented as exogenous variables that form the foundation of this theoretical model include environmental influences, education and information, government action, social pressure and market conditions.

The constructs taken from those models are the following:

1. Sustainable Consumption Behavior (SUS BEH) refers to the responsible use of goods and services to minimize environmental impact and ensure the conservation of natural resources for current and future generations.
2. Sustainable Consumption Habits (SUS HAB) refer to the practices individuals can adopt to lead more sustainable lifestyles and positively impact society. This includes actions such as consuming less, selecting products with lower environmental impacts and reducing the carbon footprint associated with everyday activities.
3. Green Purchasing (GR PURCH) refers to the practice of buying products and services that have a lower impact on human health and the environment compared to similar options. For a purchase to be considered green, it must meet specific criteria that demonstrate a reduced environmental footprint. This concept is related to consumer trends and habits, such as a growing preference for organic products over conventional ones.
4. Environmental Education and Information (ENV EDU) empowers individuals to explore environmental issues, engage in problem-solving, and take action to improve the environment. This process promotes a deeper understanding of environmental challenges and helps develop the skills necessary for making informed and responsible decisions. Key topics include awareness and sensitivity to environmental challenges,

knowledge and understanding of environmental issues, attitudes that reflect concern for the environment, and motivation to enhance or preserve the environment.

5. Environmental Influence (ENV INF) refers to various conditions in the surrounding environment, as well as structures and external sources such as friends, family, communities, and social or technological factors that can affect individual development.
6. Social Environmental Pressure (SOC PR) refers to the different conditions or groups that can influence individual development by applying various forms of pressure. Cultural and social norms also establish expectations for how individuals should behave in different contexts. Additionally, media and social networks can exert significant pressure by setting behavioral standards related to the environment.
7. Government Action (GOB AC) includes initiatives by local authorities aimed at fostering environmental stewardship among community members. These efforts seek to inspire community members to actively participate in the care of our shared environment.

Implementing this type of study enables relevant policies and actions to be designed whose aim is to promote this behavior both nationally and internationally (Tabernero et al., 2015).

This model is tested by Partial Least Squares Structural Equation Modeling (PLS-SEM) using the SmartPLS statistical software, version 4.1.0.9. Subsequently, this article details the employed materials and methods, including sample definition, data collection, the theoretical model estimation that defines the working hypotheses and the description of the PLS analysis. The results cover the assessment of the measurement and structural models, hypothesis testing and the model's goodness-of-fit evaluation. Finally, the discussion and conclusions are presented.

### 3. Materials and Methods

#### 3.1. Aim and Participants

A sample of 196 university students of technical and technological degrees (bachelor's and master's degrees) of the Universitat Politècnica de València (UPV), Spain, aged between 18 and 35 years, participated in the study. Sample distribution is shown in Table 1.

**Table 1.** Socio-demographic data of the sample.

| Indicator |                         | %     |
|-----------|-------------------------|-------|
| GD_1      | Between 18 and 24 years | 81.12 |
|           | Between 25 and 30 years | 7.65  |
|           | Over 30 years           | 6.63  |
|           | NS/NC                   | 4.59  |
| GD_2      | Degree                  | 81.12 |
|           | Master                  | 18.36 |
|           | Doctorate               | 0.51  |
| GD_3      | Female                  | 51.53 |
|           | Male                    | 47.95 |
|           | NS/NC                   | 0.51  |

For the study, a questionnaire was designed and distributed online. The questions or items included in it were obtained from other already-validated instruments (Figueroa-García et al., 2018; Kowalska et al., 2021) in the field of measuring sustainable consumption habits and their influence on the social environment. It includes 33 Likert-type scale questions, where the lowest value, 1, represents "I do not agree at all" and the highest, 5, represents "I totally agree", and there are three socio-demographic questions. Questions were grouped into eight sections (see Table 2).

**Table 2.** Indicators and definitions of the questions in the questionnaire.

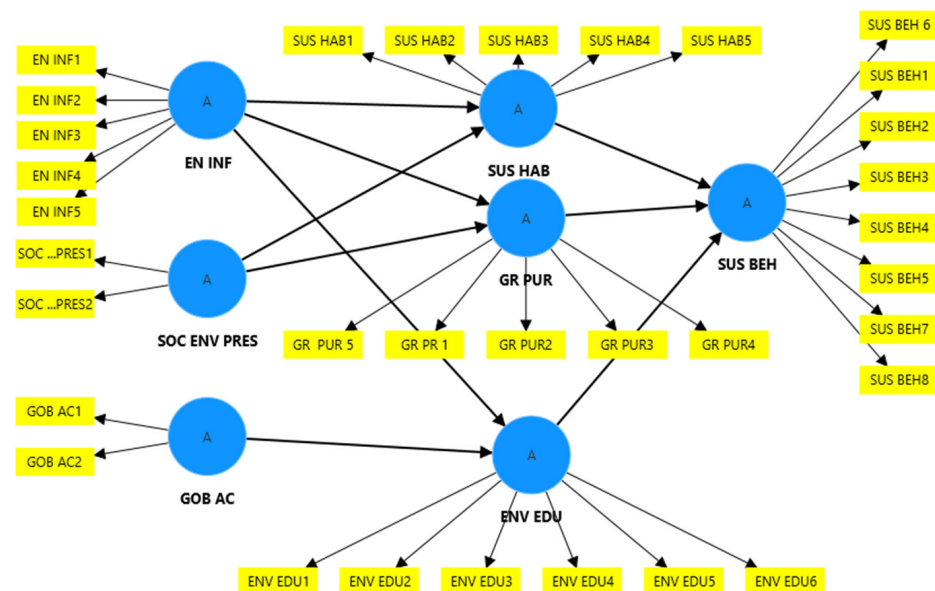
| Indicator                                         | Definition                                                                                          |
|---------------------------------------------------|-----------------------------------------------------------------------------------------------------|
| General data (GD)                                 |                                                                                                     |
| GD_1                                              | Age                                                                                                 |
| GD_2                                              | Level of education                                                                                  |
| GD_3                                              | Gender                                                                                              |
| Sustainable Consumption Habits (SUS HAB)          |                                                                                                     |
| SUS HAB_1                                         | Every day I am careful about the activities I perform to protect the environment.                   |
| SUS HAB_2                                         | I perform specific activities to protect the environment.                                           |
| SUS HAB_3                                         | I consume local products to support the economy of my area                                          |
| SUS HAB_4                                         | I consider myself environmentally responsible.                                                      |
| SUS HAB_5                                         | I consider the potential environmental impact of my actions before making decisions.                |
| Sustainable Consumption Behavior (SUS BEH)        |                                                                                                     |
| SUS BEH_1                                         | It is important for me that the products I consume do not harm the environment.                     |
| SUS BEH_2                                         | I am motivated to make changes in my lifestyle to achieve responsible consumption.                  |
| SUS BEH_3                                         | I care about wasting our planet's resources.                                                        |
| SUS BEH_4                                         | I would describe myself as an environmentally responsible and involved person.                      |
| SUS BEH_5                                         | I am willing to compromise my comfort to act in an environmentally responsible way.                 |
| SUS BEH_6                                         | I try to buy products that do not have too much packaging.                                          |
| SUS BEH_7                                         | If possible, I buy products in reusable/recyclable packaging.                                       |
| SUS BEH_8                                         | I have convinced my family and/or friends to buy responsibly.                                       |
| Environmental Influence (ENV INF)                 |                                                                                                     |
| ENV INF_1                                         | Someone in my family or friends motivates me to be environmentally friendly.                        |
| ENV INF_2                                         | I have volunteered for social work related to the environment.                                      |
| ENV INF_3                                         | Being environmentally friendly is a priority in my family.                                          |
| ENV INF_4                                         | At my usual home, waste is separated for recycling.                                                 |
| ENV INF_5                                         | At my usual home, there are always green spaces.                                                    |
| Environmental Education and Information (ENV EDU) |                                                                                                     |
| ENV EDU_1                                         | I have been taught activities to be more responsible in resources use (water, electricity, energy). |
| ENV EDU_2                                         | I am informed about the environmental problems that currently exist.                                |
| ENV EDU_3                                         | I am informed about the negative effects of certain products that I consume.                        |
| ENV EDU_4                                         | I usually pay attention to environmental advertising.                                               |
| ENV EDU_5                                         | I am aware of the advertising behind organic products.                                              |
| ENV EDU_6                                         | The use of green messages in advertising affects my attitude about that advertising.                |
| Social Environmental Pressure (SOC PR)            |                                                                                                     |
| SOC PR_1                                          | I have felt pressure from my friends to perform activities that benefit the environment.            |
| SOC PR_2                                          | I feel obliged to belong to a group of people involved with the environment.                        |
| Green Purchase (GR PURCH)                         |                                                                                                     |
| GR PUR_1                                          | I trust organic products more than conventional ones.                                               |
| GR PUR_2                                          | I think there are many places where I can find products that are not harmful to the environment.    |
| GR PUR_3                                          | I support brands that produce responsibly.                                                          |
| GR PUR_5                                          | I take advantage of the fact that I can now easily get products.                                    |

Table 2. Cont.

| Indicator                  | Definition                                                                                                  |
|----------------------------|-------------------------------------------------------------------------------------------------------------|
| Government Action (GOB AC) |                                                                                                             |
| GOB AC_1                   | In my city, the government motivates people to act responsibly through equality and social justice.         |
| GOB AC_2                   | The government is responsible for doing what is necessary so I can take action in favor of the environment. |

### 3.2. Research Model

Figure 1 illustrates the initial theoretical model, where latent variables (represented in blue) and their respective indicators (in yellow) are identified. This model was constructed based on a literature review to understand how external factors influence sustainable individual behavior. Table 1 summarizes the selected manifest variables (indicators) and latent variables (constructs) used to formulate the proposed initial model, as depicted in Figure 1.



**Figure 1.** Initial theoretical Path Model (own research adapted from (Figueroa-García et al., 2018)).

The formulation of the hypotheses in Section 3.3 is directly derived from this structural model, ensuring a clear alignment between theoretical variables and the expected relationships:

#### 1. Government Action and Environmental Education (H1-a, RQ1)

The latent variable GOB AC (Government Action) has a direct relationship with ENV EDU (Environmental Education and Information), reflecting the role of governmental policies and regulations in promoting environmental education.

This relationship justifies the hypothesis that government action positively influences environmental education and access to environmental information.

#### 2. Social Environmental Pressure and Sustainable Behavior (H2-a, H2-b, RQ2, RQ3)

The variable SOC ENV PRES (Social Environmental Pressure) influences GR PUR (Green Purchase) and SUS HAB (Sustainable Consumption Habits), suggesting that social environmental pressure can motivate the adoption of sustainable habits and green purchasing decisions.

These relationships explain H2-a and H2-b, which state that Social Environmental Pressure correlates positively with Green Purchase and Sustainable Consumption Habits.

### 3. Environmental Influence and Sustainable Habits (H3-a, H3-b, H3-c, RQ4, RQ5, RQ6)

EN INF (Environmental Influence) is related to SUS HAB (Sustainable Habits), GR PUR (Green Purchase) and ENV EDU (Environmental Education).

These connections justify hypotheses H3-a, H3-b and H3-c, demonstrating that environmental influence drives both environmental education and sustainable consumption actions.

### 4. Environmental Education and Sustainable Behavior (H4, RQ7)

ENV EDU (Environmental Education and Information) is linked to SUS BEH (Sustainable Behavior), supporting hypothesis H4, which states that environmental education has a positive impact on sustainable behavior.

### 5. Sustainable Habits and Sustainable Behavior (H5, RQ8)

SUS HAB (Sustainable Habits) influences SUS BEH (Sustainable Behavior), validating the hypothesis that sustainable habits promote overall sustainable behavior.

### 6. Green Purchase and Sustainable Behavior (H6, RQ9)

GR PUR (Green Purchase) has a direct relationship with SUS BEH (Sustainable Behavior), reinforcing the hypothesis that green purchasing decisions impact overall sustainable behavior.

### 3.3. Research Hypothesis

The inclusion of constructs and the relations between them in establishing the model is grounded in prior knowledge, research and relevant studies about motivators of Sustainable Consumption Behavior. Governments' role as either motivators for or constraints of this behavior, through the presence or absence of necessary conditions for pro-environmental actions, has been previously established (see, for example, Do Paco et al., 2019; Kollmuss & Agyeman, 2002; Steg & Gifford, 2005; Corral-Verdugo, 2012; Chen & Tung, 2010). Likewise, poorly enforcing existing regulations has been shown to have a more detrimental effect than not having regulations altogether (Vicente-Molina et al., 2013). Hence, we put forward the following hypotheses to corroborate a possible correlation:

- **RQ1 (H1-a).** Government Action correlates positively with Environment Education and Information.

Social pressure that results from the norms that form in community life can serve as a persuasive force in various aspects, from group dynamics to individual behavior (Tabernero et al., 2015). This often leads to behavior shaped by the desire to comply with these established norms, beginning with personal values and subsequently influenced by expectations imposed by reference groups, especially when individuals seek membership in these groups (Salgado Beltrán & Bravo Díaz, 2015). In this context, we can assume the following:

- **RQ2 (H2-a).** Social environmental pressure correlates positively with Green Purchase.
- **RQ3 (H2-b).** Social environmental pressure correlates positively with Sustainable Consumption Habits.

Influences that stem from the social environment may arise from friends, family and other social groups, and can shape consumer attitudes toward this context (Salgado Beltrán & Bravo Díaz, 2015). The hypotheses are, therefore, as follows:

- **RQ4 (H3-a).** Environmental Influence correlates positively with Sustainable Consumption Habits.
- **RQ5 (H3-b).** Environmental Influence correlates positively with Green Purchase.
- **RQ6 (H3-a).** Environmental Influence correlates positively with Environmental Education and Information.

On Education and Information and Sustainable Habits, some studies indicate a lack of clarity concerning the type of relation established between this variable and Sustainable Consumption Behavior. It is also widely believed that both formal and informal education, along with the availability of information on the topic, significantly influence consumer purchasing decisions (Vicente-Molina et al., 2013). Hence, we formulate the following hypotheses:

- **RQ 7 (H4).** Environmental Education and Information influence Sustainable Behavior.
- **RQ 8 (H5).** Sustainable Habits correlate positively with Sustainable Behavior.

Market conditions for sustainable products and services also demonstrate contradictory behavior (Salgado Beltrán & Bravo Díaz, 2015; Gleim et al., 2013). When making green purchasing decisions, it is important how individuals perceive the efficiency of products on this market and the factors that influence the costs of substituting one product for another (Shao et al., 2017). This leads to the following hypothesis:

- **RQ 9 (H6).** Green Purchase influences Sustainable Consumption Behavior.

### 3.4. Research Method

A confirmatory factor analysis (CFA) using structural equation modeling (SEM) was conducted to evaluate the factor structure of the 33-item scale. Two SEM approaches are available: covariance-based SEM (CB-SEM) and composite-based SEM, or PLS-SEM. This study adopts the latter (PLS-SEM) given the model's seven constructs and three items or indicators. PLS-SEM is a valuable method for predicting behaviors in behavioral research fields. For complex models that include both formative (causal) and reflective (outcome) constructs, PLS provides theoretical insights, with its primary strength lying in modeling (Gupta & Ogden, 2009; Hair et al., 2019). This technique was selected for its ability to simultaneously examine a series of dependence relations, especially when the model includes latent variables of both first and second orders (Lowry & Gaskin, 2014).

The Measurement Theory guides how to measure latent variables and includes two types of measurement models (Hair et al., 1998): formative and reflective models. In our study, all the constructs were formulated as composite type A. This allowed us to assess reliability and validity measurements.

#### Stage 1: Measurement Model

A measurement model describes the relation between indicators and each construct by assessing the reliability and validity of measures. The evaluation of the measurement model followed the following criteria (Lowry & Gaskin, 2014):

- Indicator Reliability: Outer loading for each indicator should meet or exceed 0.70 (Lowry & Gaskin, 2014).
- Internal Consistency Reliability: Assessed using Cronbach's alpha ( $\alpha$ ) and Composite Reliability (CR), with a threshold of  $\geq 0.70$  for both (Hair et al., 1998).
- Validity:
  - Convergent Validity: Average variance extracted (AVE) should be  $\geq 0.50$  (Hair et al., 2017).
  - Discriminant Validity: Verified by three methods:
    - Fornell–Larcker criterion (Hair et al., 2017);
    - Cross-loadings; (Hair et al., 1998);
    - Heterotrait-monotrait ratio (HTMT) (Hair et al., 2017).

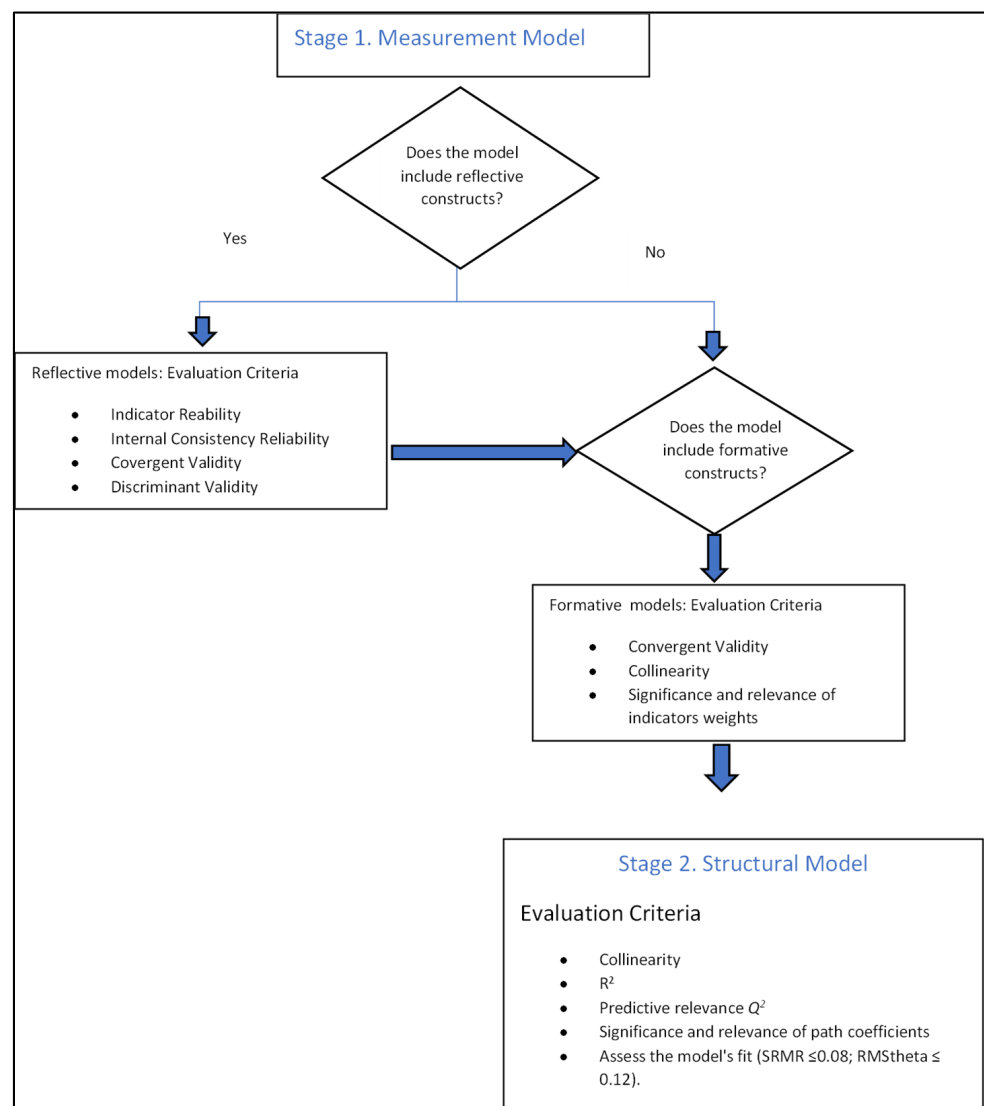
#### Stage 2: Structural Model

Structural models examine relations between constructs. The structural model was assessed following the following criteria from (Hair et al., 1998):

- Check for collinearity issues ( $VIF < 5$ );

- Evaluate the significance and relevance of the relations in the structural model ( $p < 0.05$ );
- Analyze the  $R^2$  level (with thresholds of 0.190 for weak, 0.333 for moderate and 0.670 for substantial);
- Assess  $Q^2$  values (should be over zero);
- Check the model's fit ( $SRMR \leq 0.08$ ;  $RMSt\theta \leq 0.12$ ).

Figure 2 illustrates the methodology's two stages. Stage 1 addresses the assessment of reflective and formative measurement models, with both measurement models testing the Measurement Theory. Stage 2 involves evaluating the structural model, which addresses the Structural Theory by testing the proposed hypotheses and by analyzing the relations among the latent variables (Hair et al., 1998).



**Figure 2.** PLS-SEM model evaluation (adapted from (Hair et al., 1998)).

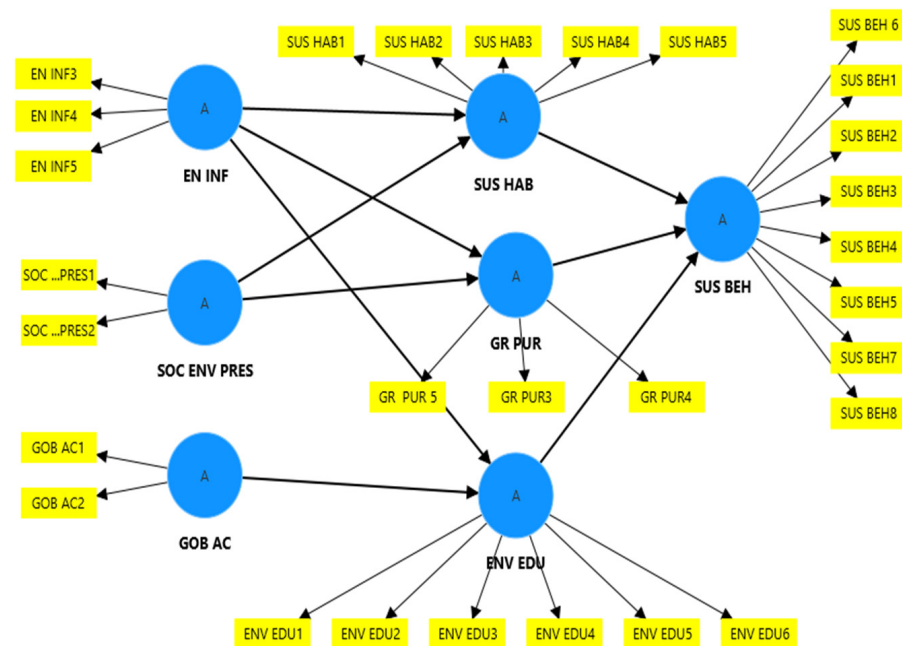
## 4. Results

### 4.1. Measurement Model

- Internal Consistency Reliability Tests

All the constructs were formulated as composite type A. Thus, outer loadings were analyzed (Lowry & Gaskin, 2014). As some outer loadings did not exceed 0.7 across items,

and Internal Consistency and Reliability (CR) and (AVE) did not reach the threshold value in some cases, the model was refined and was left as shown in Figure 3.



**Figure 3.** Redefined conceptual model.

In this model, all the outer loadings were higher than 0.7. Table 3 shows the validity and reliability measures of each construct (Cronbach's Alpha), Composite Reliability (CF) and Convergent Validity (AVE). In all cases, thresholds were exceeded (0.5 and 0.7), except for government performance because this construct was measured only with two indicators when three are recommended.

**Table 3.** Measures of the Internal Consistency Reliability test.

|              | Cronbach's Alpha | Composite Reliability (CR) | Average Variance Extracted (AVE) |
|--------------|------------------|----------------------------|----------------------------------|
| EN INF       | 0.719            | 0.778                      | 0.630                            |
| ENV EDU      | 0.812            | 0.822                      | 0.517                            |
| GOB AC       | 0.495            | 0.560                      | 0.656                            |
| GR PUR       | 0.703            | 0.762                      | 0.623                            |
| SOC ENV PRES | 0.632            | 1.124                      | 0.696                            |
| SUS BEH      | 0.886            | 0.890                      | 0.558                            |
| SUS HAB      | 0.763            | 0.782                      | 0.520                            |

#### - Discriminant Validity

The Fornell–Lacher criterion, the cross-loadings matrix and the HTMT criterion were assessed. The Fornell–Lacher criterion results appear in Appendix A (Table A1). This method uses AVE to compare the squared correlation to the other constructs in the model. With our data, the diagonal values were higher than those in the same column.

Table 4 shows the HTMT matrix. Heterotraits analyze any correlations between different constructs, and monotrait correlations measure the correlations in the same construct. Values of  $\leq 0.9$  are acceptable. The results indicated that values differed significantly from 1 in most cases.

**Table 4.** The heterotrait–monotrait ratio (HTMT) correlation matrix.

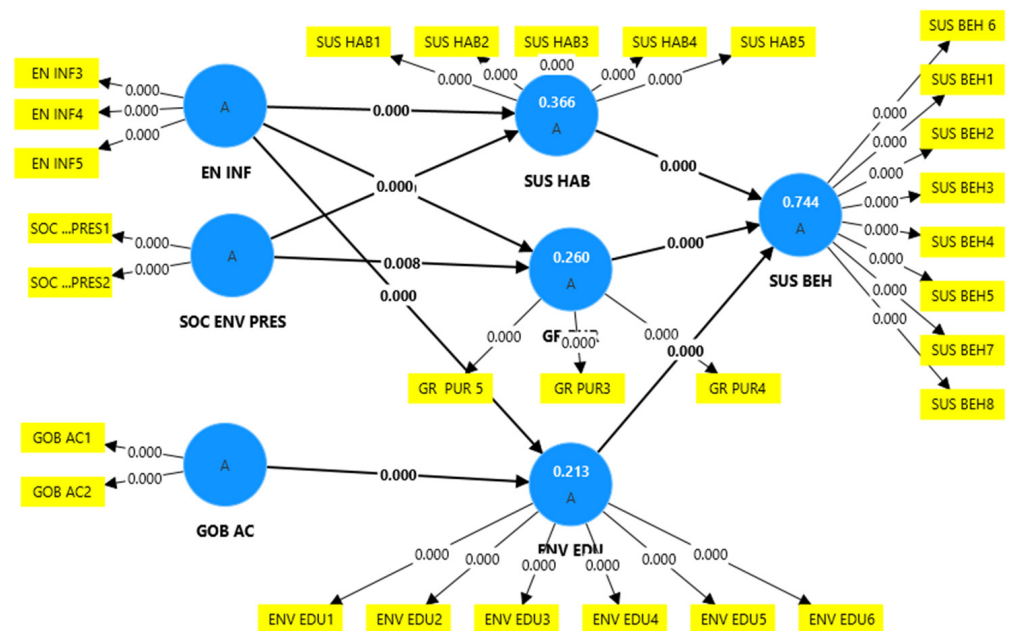
|              | EN I<br>NF | ENV<br>EDU | GOB<br>AC | GR<br>PUR | SOC ENV<br>PRES | SUS<br>BEH | SUS<br>HAB |
|--------------|------------|------------|-----------|-----------|-----------------|------------|------------|
| EN INF       |            |            |           |           |                 |            |            |
| ENV EDU      | 0.419      |            |           |           |                 |            |            |
| GOB AC       | 0.301      | 0.561      |           |           |                 |            |            |
| GR PUR       | 0.616      | 0.603      | 0.344     |           |                 |            |            |
| SOC ENV PRES | 0.319      | 0.301      | 0.333     | 0.341     |                 |            |            |
| SUS BEH      | 0.626      | 0.655      | 0.390     | 0.949     | 0.270           |            |            |
| SUS HAB      | 0.712      | 0.546      | 0.389     | 0.885     | 0.423           | 0.924      |            |

Finally, to assess the significance of loadings, the bootstrap algorithm was applied using 50,000 samples to estimate the  $t$  and  $p$  values and to, thus, check the significance of external loadings with a 5% probability of error. This means that the 5% statistical significance level indicates that  $p$ -values must be  $>0.05$  to accept the hypothesis with a  $t$  value of  $>1.65$ . The results showed that all the loadings were significant ( $p$ -value  $< 0.05$ ). In this way, the measurement model was validated.

#### 4.2. Structural Model Validation

Validating the structural model requires five steps (Lowry & Gaskin, 2014). First, evaluate collinearity using the variance inflation factor (VIF). VIF values of  $\geq 5$  indicate a possible collinearity problem (Lowry & Gaskin, 2014). The results appear in Appendix A (Table A2). As all the obtained VIF values were under 5, there were no collinearity problems.

Next the structural model must be evaluated to check the significance of the path coefficients. To do this, a Bootstrap analysis is performed. As shown in Figure 4, the  $p$ -value was estimated for each relation, and all of them were significant ( $p$ -value  $< 0.05$ ).

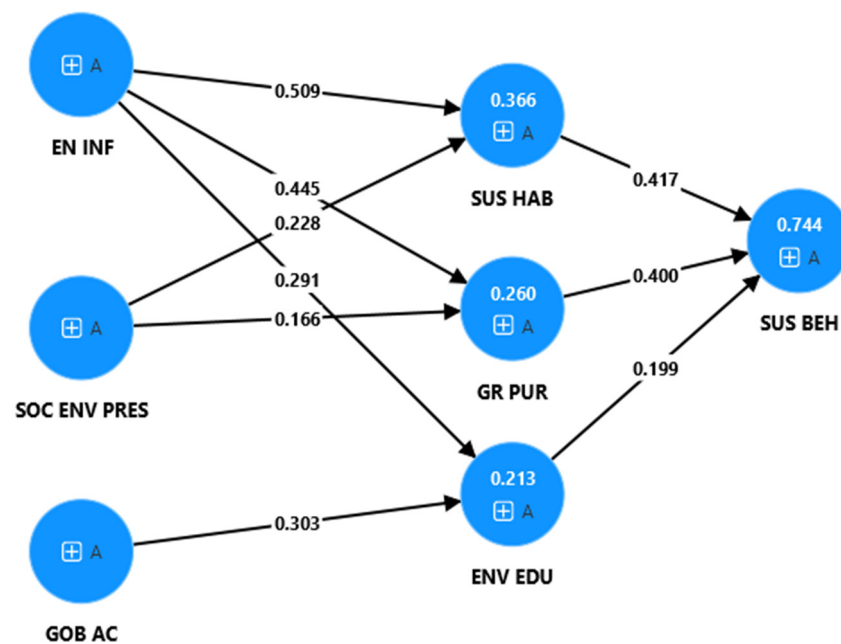
**Figure 4.** Significance testing results of each relation ( $p$ -values).

As shown in Table 5, all the hypotheses were accepted at the 5% significance level given the estimated  $p$ -value for each relation. It was verified that all the path coefficients were significant by comparing the empirical “ $t$ ” value to the critical value. When the first is higher than the second, the coefficient is considered statistically significant with a certain probability of error, i.e., significance level (Hair et al., 1998).

**Table 5.** Significance of the model parameters (*p* values).

|                         | Original Sample<br>(O) | Sample Mean<br>(M) | Standard Deviation<br>(STDEV) | T Statistics<br>( O/STDEV ) | <i>p</i> Values |
|-------------------------|------------------------|--------------------|-------------------------------|-----------------------------|-----------------|
| EN INF -> ENV EDU       | 0.291                  | 0.296              | 0.068                         | 4.281                       | 0.000           |
| EN INF -> GR PUR        | 0.445                  | 0.447              | 0.061                         | 7.341                       | 0.000           |
| EN INF -> SUS HAB       | 0.509                  | 0.513              | 0.051                         | 9.993                       | 0.000           |
| ENV EDU -> SUS BEH      | 0.199                  | 0.203              | 0.044                         | 4.535                       | 0.000           |
| GOB AC -> ENV EDU       | 0.303                  | 0.309              | 0.065                         | 4.639                       | 0.000           |
| GR PUR -> SUS BEH       | 0.400                  | 0.400              | 0.053                         | 7.489                       | 0.000           |
| SOC ENV PRES -> GR PUR  | 0.166                  | 0.169              | 0.063                         | 2.646                       | 0.008           |
| SOC ENV PRES -> SUS HAB | 0.228                  | 0.230              | 0.059                         | 3.893                       | 0.000           |
| SUS HAB -> SUS BEH      | 0.417                  | 0.415              | 0.050                         | 8.310                       | 0.000           |

Then, the coefficients of determination ( $R^2$ ) of the dependent factors of the theoretical model were evaluated. This provides their amount of variance, which is explained by the independent factors, and can be interpreted as an indicator of the proposed model's predictive accuracy by taking values of the order of 0.75 as being substantial, of the order of 0.5 as moderate and of the order of 0.25 as weak (Hair et al., 1998). As Figure 5 depicts, 74.4% of Sustainable Consumption Habits (SUS BEH) were explained by Sustainability Habits, Green Purchase, and Environment Education and Information, which were, in turn, influenced by Government Action.

**Figure 5.** Coefficients of determination of the dependent factors of the theoretical model proposed to evaluate the determinants of sustainable consumption.

The fourth step assessed predictive relevance, i.e.,  $Q^2$ , using blindfolding. If the  $Q^2$  value is 0.02, it indicates minor predictive relevance, values of 0.15 imply medium relevance and values of 0.35 denote considerable predictive relevance (Gupta & Ogden, 2009). Table A2 shows the  $Q^2$  for the latent variables.

Finally,  $Q^2$  was examined to assess the structural model's predictive relevance as an additional predictive criterion to  $R^2$ . The predictive relevance of the constructs must be positive with values above zero. Values of 0.02 are taken as small values, values of 0.15 are medium values and those of 0.35 are large values when considering the model's predictive validity (Gupta & Ogden, 2009; Hair et al., 2017).

To determine this, it is necessary to generate the blindfolding procedure, which demonstrates model items' predictive precision. A  $Q^2$  of 0.293 was obtained for the Sustainable Consumption Habits (SCH) factor and one of 0.349 was obtained for the Sustainable Habits construct when considering an almost strong average prediction, (Table 6).

**Table 6.** Results of  $Q^2$ , predictive relevance.

|         | $Q^2$ Predict | RMSE  | MAE   |
|---------|---------------|-------|-------|
| ENV EDU | 0.181         | 0.911 | 0.703 |
| GR PUR  | 0.235         | 0.884 | 0.710 |
| SUS BEH | 0.293         | 0.854 | 0.665 |
| SUS HAB | 0.349         | 0.818 | 0.645 |

To evaluate the model's fit, we applied a series of fit indices as outlined by (Chin & Newsted, 1999), as follows:

- The Standardized Root Mean Square Residual (SRMR). In this study, the SRMR was 0.082, which is below the threshold of 0.10 recommended by (Lohmöller, 1989).
- The Normed Fit Index (NFI), as proposed by (Chin & Newsted, 1999). Higher values close to 1 indicate a better fit, with values above 0.9 representing an acceptable fit level (Lohmöller, 1989; Hu & Bentler, 1999). Here, the NFI value was 0.658.

We also examined the model's goodness-of-fit (GoF), defined as "the extent to which the proposed model reproduces the observed covariance matrix among the indicator variables" (Hair et al., 1998). In this model, GoF was 0.45, which exceeded the threshold value of 0.35 suggested by (Bentler & Bonett, 1980) and indicates strong overall performance and a substantial fit.

## 5. Discussion

This paper analyzes the impact of Sustainable Habits, Green Purchase, Environmental Education and Information, Environmental Influence, Social Environmental Pressure and Government Action on Sustainable Behavior by proposing a PLS-SEM model. It presents a new conceptualization of the SUS BEH construct that differs from previous research because it considers Sustainability Habits, Green Purchase and Environmental Education and Information, Social Environmental Pressure, Government Action and Environmental Influence as the relevant factors used to construct an initial theoretical model.

The relationships between the exogenous and the endogenous variables of Sustainable Behavior and structural equations were assessed using Partial Least Squares (PLS-SEM) modeling.

All five initially proposed hypotheses were confirmed. So, we can state that Sustainable Consumption Behavior was determined by Environmental Education and Information ( $t = 4.535$ ), understood as Education for Sustainable Development and Green Purchase ( $t = 7.489$ ), which refer to positive consumer perceptions of sustainable products and Sustainable Consumption Habits ( $t = 8.310$ ) which are related to the behavior and buying habits of consumers to minimize harm to the environment. In addition, Government Action ( $t = 4.639$ ) contributes to Environmental Education and Information and Social Environmental Pressure contributes to Green Purchase ( $t = 2.643$ ) and Sustainable Consumption Habits ( $t = 2.646$ ). These research findings are supported by the literature identified above. Finally, Environmental Influence, particularly interested in studying the effects of family and friends, contributes to Sustainable Consumption Habits ( $t = 9.993$ ), Green Purchase ( $t = 7.341$ ) and Environmental Education and Information ( $t = 4.281$ ).

The research confirmed that the original scale proposed by (Figueroa-García et al., 2018) could be adapted to assess Sustainable Consumption Behavior, and moreover, it was proved that the modified proposed model retained a good model fit in studies on young consumers in other countries with different backgrounds.

The findings of this study provide new insights into the determinants of Sustainable Consumption Behavior among university students, highlighting the role of environmental education, green purchasing habits, social environmental pressure, and governmental actions. These results not only validate the proposed PLS-SEM model but also contribute to the broader discourse on sustainable development, particularly in achieving SDG12 (Responsible Consumption and Production).

A key contribution of this research is the confirmation that Environmental Education and Information plays a crucial role in shaping sustainable behavior. This finding aligns with previous studies emphasizing the need for well-structured educational programs to raise awareness about environmental issues and responsible consumption. Given the increasing focus on sustainability in higher education institutions, our study suggests that curricula should integrate sustainability-oriented courses, practical experiences, and interdisciplinary approaches to foster students' awareness and engagement with sustainability.

Furthermore, the study confirms that Green Purchase and Sustainable Consumption Habits significantly impact sustainable behavior, indicating that students who are more conscious of the environmental impact of their purchases are more likely to adopt sustainable consumption patterns. This reinforces the idea that educational institutions and policymakers should collaborate to promote responsible consumer choices through campus-wide sustainability campaigns, green certifications for student organizations and incentives for sustainable consumption.

Another relevant insight is the influence of social and environmental pressures on sustainable consumption. The significant effect of Environmental Influence from family and peers suggests that social networks play a vital role in shaping students' consumption patterns. This has implications for educational methodologies, as collaborative learning strategies and peer-led sustainability initiatives can amplify the impact of formal education. Universities should consider implementing mentorship programs where environmentally conscious students can guide their peers in making sustainable choices.

Additionally, Government Action was found to positively contribute to environmental education and awareness. This suggests that public policies aimed at promoting sustainable consumption should be reinforced through educational campaigns, subsidies for sustainable products, and stricter environmental regulations. Such measures could complement university efforts by creating an external framework that supports and reinforces sustainable behavior.

Despite these findings, some limitations should be acknowledged. This study was conducted within a specific university context, and future research should explore whether similar trends emerge among students from different regions and educational backgrounds. Additionally, further studies could examine the long-term impact of sustainability education on students' post-graduate consumption behaviors.

## 6. Conclusions

In this paper, we propose and test a framework that explains the role of Sustainable Behavior and the main factors that correlate with it. This study extends sustainable consumption research by developing and validating a sustainable consumption model that consists of seven main dimensions or factors: Sustainable Consumption Behavior (SUS BEH), Sustainable Consumption Habits (SUS HAB), Green Purchase (GR PURCH), Envi-

ronmental Education and Information (ENV EDU), Environmental Influence, (ENV INF), Social Environmental Pressure (SOC PR) and Government Action (GOB AC).

This research confirms that Sustainable Consumption Behavior among university students is strongly influenced by Environmental Education and Information, Green Purchase, and Sustainable Consumption Habits. Moreover, Social Environmental Pressure, and Environmental Influence, along with Government Action, significantly contribute to shaping sustainable attitudes and behaviors.

The implications of these findings extend beyond academia, providing valuable insights for educators, policymakers, and industry stakeholders. Universities should incorporate sustainability education into their curricula and promote student-led sustainability initiatives to enhance awareness and behavioral change. Policymakers should develop strategies that integrate education, regulation and incentives to foster sustainable consumption at a broader level.

In alignment with the United Nations (2023), this study underscores the necessity of intensifying efforts to integrate sustainability principles into education. By identifying the key motivators behind sustainable consumption, governments, institutions, and businesses can design targeted interventions that drive meaningful and long-lasting environmental, economic, and social benefits.

Future research should consider expanding the sample to include students from diverse academic disciplines and geographical locations. Additionally, longitudinal studies could assess the evolution of Sustainable Consumption Behaviors over time, providing deeper insights into the long-term effectiveness of sustainability education.

Overall, this study contributes to the growing body of knowledge on sustainability in higher education, reinforcing the importance of integrating educational, social, and policy-driven approaches to promote Sustainable Consumption Behaviors among young consumers.

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**Institutional Review Board Statement:** The research was conducted following the principles embodied within the Declaration of Helsinki and according to local statutory requirements. This study was approved by the UPV Research Ethics Committee.

**Informed Consent Statement:** All the participants gave written informed consent to participate in the study. Participation in the study was voluntary, and participants could withdraw at any point. The online survey was completely anonymous and did not contain any information that could allow participants’ identification.

**Data Availability Statement:** The authors confirm that the data supporting the findings of this study are available in the article.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## Abbreviations

|                |                                                    |
|----------------|----------------------------------------------------|
| AVE            | Average variance extracted                         |
| CB-SEM         | Covariance-based and structural equation modeling  |
| CFA            | Confirmatory Analysis                              |
| CR             | Composite Reliability                              |
| GoF            | Goodness of fit                                    |
| HTMT           | Heterotrait–monotrait ratio                        |
| PLS            | Partial Least Square                               |
| Sustainability | 2022, 14, 13261 20 of 28                           |
| PLS-SEM        | Partial Least Square and structural equation model |
| Q <sup>2</sup> | Goodness of PLS prediction                         |
| QoI            | Quality of Interaction                             |
| R <sup>2</sup> | Determination Coefficient                          |
| RMS            | Root Mean Square                                   |
| SRMR           | Standardized Root Mean Residual                    |
| VIF            | Variance inflation factor                          |
| SUS BEH        | Sustainable Behavior                               |
| SUS HAB        | Sustainable Habits                                 |
| GR PURCH       | Green Purchase                                     |
| ENV EDU        | Environmental Education and Information            |
| ENV INF        | Environmental Influence                            |
| SOC ENV PR     | Social Environmental Pressure                      |
| GOB AC         | Government Action                                  |

## Appendix A

**Table A1.** Fornell–Lacker discriminant validity correlation matrix.

|              | EN INF | ENV EDU | GOB AC | GR PUR | SOC ENV PRES | SUS BEH | SUS HAB |
|--------------|--------|---------|--------|--------|--------------|---------|---------|
| EN INF       | 0.793  |         |        |        |              |         |         |
| ENV EDU      | 0.354  | 0.719   |        |        |              |         |         |
| GOB AC       | 0.210  | 0.364   | 0.810  |        |              |         |         |
| GR PUR       | 0.484  | 0.473   | 0.219  | 0.789  |              |         |         |
| SOC ENV PRES | 0.238  | 0.225   | 0.209  | 0.272  | 0.834        |         |         |
| SUS BEH      | 0.538  | 0.566   | 0.275  | 0.774  | 0.228        | 0.747   |         |
| SUS HAB      | 0.563  | 0.426   | 0.257  | 0.670  | 0.349        | 0.770   | 0.721   |

**Table A2.** Collinearity (VIF) analysis.

|          | VIF   |
|----------|-------|
| EN INF3  | 1.349 |
| EN INF4  | 1.466 |
| EN INF5  | 1.433 |
| ENV EDU1 | 1.346 |
| ENV EDU2 | 1.765 |
| ENV EDU3 | 1.809 |
| ENV EDU4 | 2.128 |
| ENV EDU5 | 1.669 |
| ENV EDU6 | 1.914 |
| GOB AC1  | 1.121 |
| GOB AC2  | 1.121 |
| GR PUR 5 | 1.346 |
| GR PUR3  | 1.341 |
| GR PUR4  | 1.453 |

Table A2. Cont.

|               | VIF   |
|---------------|-------|
| SOC ENV PRES1 | 1.272 |
| SOC ENV PRES2 | 1.272 |
| SUS BEH 6     | 1.920 |
| SUS BEH1      | 1.668 |
| SUS BEH2      | 2.927 |
| SUS BEH3      | 1.915 |
| SUS BEH4      | 2.367 |
| SUS BEH5      | 2.246 |
| SUS BEH7      | 1.930 |
| SUS BEH8      | 1.579 |
| SUS HAB1      | 1.687 |
| SUS HAB2      | 1.381 |
| SUS HAB3      | 1.205 |
| SUS HAB4      | 1.819 |
| SUS HAB5      | 1.457 |

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## Systematic Review

# Successful Educational Actions for Sustainable Development: A Systematic Review of Training for Employability Development of Vulnerable Groups

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**Abstract:** Successful Education Actions (SEAs) have proven to be key to generating opportunities for vulnerable groups. Building a sustainable future requires ensuring inclusive education that addresses inequalities and fosters social cohesion, aspects that SEAs promote by addressing educational and occupational inclusion. Recent studies underline the effects of SEAs on education and social cohesion. However, their impact on employability development has been insufficiently explored. Therefore, this study presents a systematic review that explores how SEAs contribute to the development of transversal competences that improve the employability of people in vulnerable situations, impacting on three dimensions: individual characteristics, personal circumstances, and contextual factors. PRISMA2020 methodology was used, and 30 empirical articles were analysed. After analysis, the results show that the high social and educational expectations, participation, quality relationships, community engagement, and co-creation promoted by SEAs have a significant impact on the employability of participants. These factors can contribute to more sustainable cities by fostering inclusive and lasting employability. The study systematises the positive effects of SEAs on employability and proposes optimal educational strategies that facilitate informed decisions for managers and policy makers.

**Keywords:** education for sustainability; employability; vulnerable groups; successful educational actions



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## 1. Introduction

Building a sustainable future has led the United Nations (UN) to lead a global effort to ensure that no one is left behind due to inferiority or discrimination. It involves building sustainable cities that focus on meeting the needs of their inhabitants by, among other things, securing employment and being able to participate actively in productive and social dynamics, promoting shared prosperity and stability. Spain is a multicultural country characterised by diversity, intensified in recent decades due to the increase in migratory flows. This reality is especially reflected in the classroom, where the coexistence of multiple cultures generates both challenges and opportunities for the educational system. Social inequality and the vulnerability of certain groups are of particular concern. On the one hand, foreign students, who represent 11% of the student body, present significant barriers to linguistic and cultural integration. This group is overrepresented in programmes such as Basic Vocational Training and has a low presence in the Baccalaureate, showing structural

inequalities in access and academic progression (Mahía & Medina, 2022). On the other hand, around 40% of Roma students leave school at the age of 16, a figure much higher than the national average of 13.3%. This group also suffers educational segregation and a lack of continuity in post-compulsory studies, perpetuating their social exclusion (Fundación Secretariado Gitano, 2023). These inequalities in the educational sphere have a direct impact on access to employment. Educational inequalities directly affect employment opportunities, influencing the living and working conditions that shape a community's quality of life.

The better the conditions in which a community lives and works, the greater the impact on the quality of life of its members. However, ensuring these conditions is impossible without inclusive learning that combats inequalities (ONU, n.d.). In this sense, Successful Education Actions (SEAs) have proven successful in educational inclusion, especially in vulnerable populations. Recent studies highlight the impacts of SEA on training, social cohesion, and the construction of an active citizenry capable of participating in the transformation of their environment (see, e.g., Morlà-Folch et al., 2022; Natividad-Sancho et al., 2024; Ramírez & Marín, 2022; Soriano et al., 2022). However, the impact of SEAs on employability development has not been explored. In this sense, our study carries out a documentary analysis of papers. The aim of the study was to analyse the impact of SEAs on the employability of vulnerable working-age groups. A transformative education enhances people's preparation for the world of work. It reduces structural inequalities by generating participatory dynamics that enhance collective well-being through the involvement of the entire educational community. Ensuring access to equitable opportunities and effective participation and learning spaces for all citizens, regardless of age and social background, builds a path to shared prosperity that connects education and employment with sustainable development goals.

### *1.1. Walking Towards Sustainability: Challenges and Progress in Education for the Employability of Vulnerable Groups*

The United Nations 2030 Agenda for Sustainable Development underlines equality as a fundamental pillar for building sustainable societies, highlighting the need for inclusive, quality education that enables all people to access new opportunities throughout their lives (ONU, n.d.). Within this framework, one of the drivers of social equality, quality, and individual progress is the promotion of employability and the attainment of employment (Rodrigo, 2018). Its importance drives a multitude of labour, social, and educational policies aimed at increasing the employability of citizens, with a priority focus on supporting the most vulnerable groups (e.g., ethnic minorities) (Ministerio de Trabajo y Economía Social, 2021). However, despite the importance of this phenomenon, neoliberalism attributes the responsibility of being employable to the individual (Fugate et al., 2004; Llinares et al., 2016), reducing the concept of employability to the individual's capacity to take advantage of the education and training opportunities available to him or her to access and remain in the labour market (International Labour Organization [OIL], 2004). While the ILO urges governments to improve such opportunities, most interventions aimed at increasing employability are oriented towards the adaptive training (11) of personal skills to facilitate access to employment (Díaz & López, 2021; Jurado & Olmos, 2014; Observatorio de las Ocupaciones, 2023). In this way, the employability debate is reduced to technical questions of individual efficiency that prioritise rapid advances in insertion (Bonvin & Orton, 2009) with relatively limited effects on the achievement of sustainability for those furthest away from the labour market (Fuertes et al., 2021; Lindsay et al., 2019).

However, the concept of employability has been broadened and enriched by several studies that highlight the relevance of external factors and personal circumstances (e.g., changing and temporary labour market demands, family responsibilities, housing

availability or social support) (Hillage & Pollard, 1998; McQuaid & Lindsay, 2005; González-Navarro et al., 2023). Although still in the minority, interventions targeting vulnerable populations are emerging that broaden their scope beyond the individual and adaptive and also address situational and contextual factors, adopting relational perspectives that give a central role to community interactions (Cottam, 2011, 2018; Pearson et al., 2023). Some of these initiatives are based on Sen's (2000) capabilities approach. From this approach, they promote the whole person's well-being and favour a more sustainable employability that aligns with personal realities and has more significant transformative potential. From this holistic approach, the Bioecological Model of Employability is proposed (Llinares et al., 2016, 2020).

The Bioecological Model defines employability as a social construct that is linked to the ability to acquire and maintain a job. This capacity is generated from the reciprocal interaction between the person, understood as an active and biopsychological human organism in development, and their immediate external environment, composed of people, objects, and symbols. From this perspective, employability is approached holistically by considering its three dimensions: individual characteristics, personal circumstances, and contextual factors. Thus, the competencies that make up employability include perseverance, stress tolerance, work readiness, academic background, learning to learn, time and task management, initiative, performance appraisal, autonomy, self-esteem, self-care, social and technical skills, work experience, flexibility, and the ability to work in a team. This holistic approach emphasises that employability depends not only on individual qualities but also on the opportunities and conditions generated by the social and employment context.

The ideas of Cottam (2011), developed in terms of 'relational employability' by Pearson et al. (2023), complement this framework by emphasising the crucial role of human relationships and shared values in personal and community well-being and development. This proposal argues that overcoming poverty and exclusion goes beyond providing resources or employment. It involves creating environments where human relationships and shared values are fundamental to personal and community progress. It also calls for strategies that move away from a focus solely on work-first activation and welfare conditionality, which often fail to adequately address the structural and personal barriers faced by vulnerable groups. Instead, it proposes a rethinking of the relationship between employability services and individuals, prioritising the co-creation and personalisation of interventions. This alternative model seeks to empower participants not only in access to employment but also in broader dimensions such as mental well-being (personal and family), relationship building, people's active contribution to their communities, and strengthening their capacities. It highlights the positive impact of a socially connected life, where people feel respected, supported, and empowered to contribute to their environment and reach their full potential. This is achieved through a commitment to generating meaningful learning opportunities and jobs aligned with people's values and motivations. It also recognises the importance of mutually supportive relationships as a key source of resilience. These relationships are essential for overcoming situations of exclusion or vulnerability while strengthening individuals and communities and fostering more substantial and equitable social cohesion. Therefore, a sustainable education should prepare people for a dynamic labour market while fostering practises and values that promote holistic well-being and social cohesion through the development of meaningful social relationships. This approach not only supports personal development but also enhances employability by fostering the development of transversal competencies that are essential tools for navigating diverse environments and addressing complex challenges in the workplace.

### 1.2. Successful Education Actions: Education for Employability and Sustainability

SEAs are defined as evidence-based interventions that have demonstrated their ability to improve school success and foster social cohesion in the contexts where they are implemented. These actions, identified by the European research project INCLUD-ED (2006–2011), demonstrated significant success in schools with and without disadvantaged multicultural contexts in 14 European countries (Flecha, 2015). Their impact goes beyond the academic sphere, fostering inclusive and equitable dialogical interactions involving the whole community (families, teachers, students, volunteers and other social actors) in various socio-educational activities and spaces within the community. They promote a collective commitment oriented towards high educational and social expectations to positively transform the environment (Díez et al., 2011; Morlà-Folch et al., 2022; Racionero & Padrós, 2010; Valls-Carol et al., 2014).

Types of SEAs include community educational participation, interactive groups (IG), dialogic discussion groups (DG), extended learning times, a dialogic model of conflict prevention and resolution (DMCPR), family education, and dialogic pedagogical training (Morlà-Folch et al., 2022). As has been demonstrated in numerous research studies, their implementation is successful. Their impact has been widely recognised and documented in recent research (e.g., Domínguez, 2018; Salceda et al., 2022 in childhood and adolescence). Moreover, the success of the dialogical foundations on which SEAs are based has been documented since their origin in the adult community setting. Studies in this context highlight their impact on instrumental learning, the creation and strengthening of social relationships and solidarity, and the promotion of community participation that achieves emancipatory outcomes (see, e.g., Fontes de Olivera et al., 2024; Gómez-Cuevas & Valls-Carol, 2022; Tellado, 2017), generating a deep sense of usefulness that fosters greater self-esteem and personal well-being (see Cantero et al., 2018).

These properties of SEAs, aimed at overcoming inequalities and social justice (R. Flecha & Villarejo, 2015), applied to the field of employability, would be aligned with socio-educational interventions focused on individual characteristics which, as indicated in Llinares et al. (2020), are the most common and widely valued from a technical perspective oriented towards labour market insertion, but also with relational approaches attentive to circumstantial and contextual factors with a notable potential for social transformation and community sustainability (Cottam, 2011, 2018; Pearson et al., 2023).

## 2. Materials and Methods

### 2.1. Research Design, Protocol, and Registry

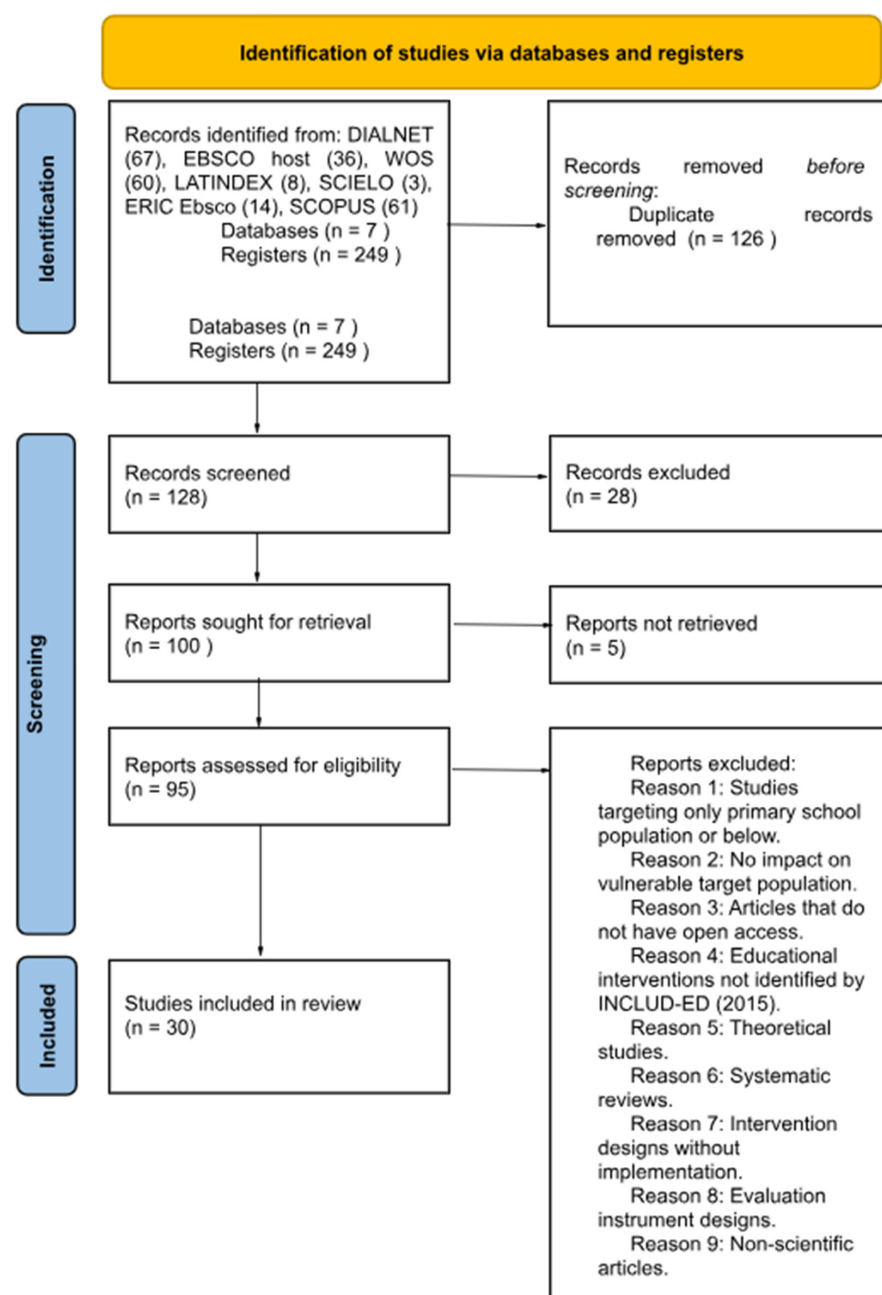
The systematic review used the PRISMA 2020 method (Page et al., 2021). In accordance with the objective of the study, the following research question was posed: Does the impact of SEAs encompass the three main dimensions that influence employability (individual, circumstantial, and contextual factors), thus contributing to the reduction in social and labour inequalities through a sustainable intervention? For this purpose, the PICO tool was used, complemented with the SPIDER model, as it is qualitative research (Cooke et al., 2012). The protocol was uploaded and registered in Open Science Framework (OSF).

### 2.2. Search Strategy and Information Sources

A literature search was conducted in October 2024 and at the end of December 2024 in the following databases: Web of Science (WOS), Scopus, Education Resources Information centre (ERIC), Scielo, EBSCO host, Latindex, and Dialnet.

The search equation was ‘Actuaciones Educativas de Éxito’, ‘Actuación Educativa de Éxito’, ‘Successful Educational Actions’, and ‘Successful Educational Action’. Quotation marks were used to ensure that the results matched the term exactly. The search was

conducted in English and Spanish, singular and plural. First, the library services of the Universitat de València suggested the following search equation: (successful OR effective OR evidence-based) AND (education\* OR school\*) AND (action\* OR practice\* OR intervention\* OR strateg\*). We searched the WOS database with that search equation and the results obtained in title were 3117 results. These results were not very restrictive and did not agree, for the most part, with the objective of the study. Therefore, in a second step, the search equation was adjusted to that mentioned above. Two of the authors independently searched the databases, yielding a total of 249 records. After eliminating duplicates, we obtained the first sample of 128 publications. Subsequently, the full texts of 95 articles were downloaded, thus initiating a first round of reading aimed at identifying those empirical studies that specified both the research group and the research context. As a result, some additional records were excluded, resulting in a final sample of 30 articles that were selected for in-depth content analysis (see Figure 1).



**Figure 1.** Flow diagram of literature search and selection process.

### 2.3. Eligibility Criteria and Study Selection Process

Inclusion and exclusion criteria were defined. To be included, the articles had to meet the following criteria: report on the impact of SEAs (Criteria 1) on people of working age (Criteria 2), which also included studies with secondary school students, whose age in Spain ranges from 12 to 16 years, being from 16 years of age when an adolescent can work; be exclusively empirical studies (Criteria 3); and address vulnerable groups and contexts (Criteria 4). In addition, we included studies whose abstract evidenced a possible impact on young people and adults participating as family members and/or volunteers in SEAs at any stage of schooling. The selection process of the studies involved three researchers, the authors of the research, who independently selected the articles. The selection of articles was consensual when all three judges agreed, and discrepancies were resolved through a dialogue between two researchers. Each explained her interpretation of the criteria until an agreement was reached. In disagreement, the title and abstract were read together, and the criteria were applied jointly to reach a solution. Then, to analyse the quality of the evidence, we used the Critical Appraisal Skills Programme (2024) method.

### 2.4. Process of Data Extraction and Data Analysis

A content analysis was conducted to analyse the articles included in the search. This approach was used to identify thematic patterns and to classify the contents into representative categories. The categorisation system designed was based on essential principles, for example, completeness, mutual exclusion, consistency, relevance, objectivity, fidelity, replicability, and productivity (Fox, 1981; Krippendorff, 1980). In the context of qualitative methodology and considering the fundamental role of the researcher in the analysis of the results, emphasis was placed on the identification and differentiation of themes, which facilitated the organisation of the information into categories. To this end, a hierarchical structure was established that distinguished between general categories and specific subcategories, following an inductive coding approach.

The development of the codebook was carried out using a hybrid approach, avoiding the use of pre-coding before data collection. It allowed codes to emerge directly from the collected material, which aligns with Cisterna's recommendations (Cisterna, 2005). This procedure was aligned with the guidelines proposed by Anguera (Anguera, 2003), starting with a coding system based on SEAs types, the Bioecological Model of Employability (Llinares et al., 2016, 2020), and Cottam's (2011, 2018) contributions to relational well-being, all following a review of the results obtained. Additionally, codes derived from other themes identified in the process were incorporated (Fereday & Muir-Cochrane, 2006). Their credibility and methodological rigour characterised the results obtained.

The information collected was classified and coded into three main categories (Individual competencies, Personal Circumstances, and Contextual Factors) and 25 subcategories, facilitating a clear and detailed structuring of the data (Table 1). From the outset, an Excel file was created to record the studies found. Duplicate studies were eliminated, and the literature was screened according to the inclusion and exclusion criteria. Two investigators independently analysed the data from each paper. If there were discrepancies, these were analysed together until they reached agreement.

**Table 1.** Categories and sub-categories indicating impact on employability.

| Category               | Subcategories                                                       |
|------------------------|---------------------------------------------------------------------|
| Individual factors     | (1) Perseverance                                                    |
|                        | (2) Stress tolerance (including self-control)                       |
|                        | (3) Academic training                                               |
|                        | (4) Learning to learn                                               |
|                        | (5) Time management                                                 |
|                        | (6) Task management                                                 |
|                        | (7) Initiative                                                      |
|                        | (8) Willingness and readiness to work                               |
|                        | (9) Performance appraisal                                           |
|                        | (10) Autonomy                                                       |
|                        | (11) Self-esteem                                                    |
|                        | (12) Self-care                                                      |
|                        | (13) Social skills                                                  |
|                        | (14) Technical skills (includes digital skills)                     |
|                        | (15) Work experience                                                |
|                        | (16) Flexibility                                                    |
|                        | (17) Teamwork                                                       |
| Circumstantial factors | (18) Work culture                                                   |
|                        | (19) Access to resources                                            |
|                        | (20) Social capital                                                 |
|                        | (21) Access to social networks                                      |
| Contextual factors     | (22) Relational factors that enhance personal and mental well-being |
|                        | (23) Contribution to overcoming stigmas                             |
|                        | (24) Access to quality educational interventions                    |
|                        | (25) Response to social needs                                       |

### 3. Results

The influence of SEAs on the development of the employability of vulnerable people of working age was analysed in the 30 articles included in this study. According to the objective, the following research question was posed: Does the impact of SEAs cover the three main dimensions that influence employability (individual, circumstantial, and contextual factors), thus contributing to the reduction in social and labour inequalities through a sustainable intervention? Table 2 presents the main characteristics of the studies included in this search. To structure the results of the study, the categorization detailed in Table 1 was used, following the Bioecologic Model of Employability (Llinares et al., 2016, 2020) and Cottam's contributions (Cottam, 2011, 2018) and relational well-being: (1) individual competencies, (2) personal circumstances, and (3) contextual factors. The first category, individual competencies, covers those indicators related to attitudinal or aptitudinal variables that are directly linked to the labour competencies necessary for employability. Secondly, the category of personal circumstances includes socio-family aspects that influence individual factors and determine, to a large extent, a person's ability to integrate into the labour market. Finally, contextual factors include external indicators such as labour market conditions in a specific context and the dimensions of the macrosystem that affect both the attainment and maintenance of employment. In the presentation of the results, we begin with an analysis of each category through a synthesis of the findings obtained in each one and then proceed to describe them in detail.

**Table 2.** Summary of the study characteristics.

| Study                           | Method * | Country               | SEA **       | Context                                                                                           | Impact on the Type of Vulnerable Population Under Study                     |
|---------------------------------|----------|-----------------------|--------------|---------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|
| (Ramírez & Marín, 2022)         | 1        | Columbia              | 1            | Schools: situational context of regional gaps and poverty.                                        | Secondary school families and students.                                     |
| (Zubiri-Esnaola et al., 2020)   | 1        | Spain                 | 2            | Schools: low socio-economic level and high percentage of immigrant pupils and families.           | Local and migrant family members.                                           |
| (Natividad-Sancho et al., 2024) | 1        | Spain                 | 1, 2, 4      | School: socio-economically disadvantaged and predominantly Roma neighbourhood.                    | Roma students in their final year of secondary school.                      |
| (Valero et al., 2018)           | 1        | Spain                 | 2            | School: more than 30% migrant students.                                                           | Migrant secondary and high school students.                                 |
| (Sánchez, 2018)                 | 1        | Columbia              | 5            | School: social context characterised by exclusion, because of violence, forced displacement, etc. | 14- and 16-year-old students.                                               |
| (Valls-Carol et al., 2014)      | 3        | 14 European countries | 1, 2, 3.1, 4 | Schools: includes schools in disadvantaged multicultural contexts.                                | Population in vulnerable situations and population without difficulties.    |
| (Sampé et al., 2012)            | 1        | Spain                 | 1, 2, 3.1    | Schools: migrant community.                                                                       | Migrant population: family members and secondary school students.           |
| (Girbés-Peco et al., 2015)      | 1        | Spain                 | 1            | Neighbourhood characterised by poverty, vulnerability, and social exclusion.                      | Young people up to 18 years old and families (Roma and migrants).           |
| (Vieites et al., 2021)          | 1        | Portugal              | 1            | Schools in vulnerable contexts of priority attention.                                             | Families from vulnerable environments.                                      |
| (R. Flecha et al., 2012)        | 1        | Spain                 | 3.1          | Prison.                                                                                           | National and migrant prison population.                                     |
| (Gómez-González et al., 2022)   | 3        | Spain                 | 6            | Schools with cultural minorities students.<br>Migrant and Roma families.                          | Roma and migrant families.                                                  |
| (Zubiri-Esnaola et al., 2023)   | 1        | Spain                 | 3.1          | Hospital.                                                                                         | Adult population. Mental health patients.                                   |
| (Racionero, 2015)               | 1        | Spain                 | 3.1          | Vulnerable context.                                                                               | Homeless person.                                                            |
| (Salceda et al., 2022)          | 1        | Spain                 | 3.1          | Out-of-home care institution.                                                                     | Adolescent girls 15–18 years old in residential care (severely neglected).  |
| (De Botton et al., 2014)        | 1        | Spain                 | 3.1          | School: neighbourhood with low socio-economic status.                                             | Moroccan mothers with low levels of schooling, some of whom are illiterate. |
| (Garcia-Yeste et al., 2018a)    | 1        | Spain                 | 3.1, 6       | School: majority of families and students of minority ethnicity.                                  | Vulnerable mothers from minority ethnic backgrounds.                        |
| (Ocampo-Castillo et al., 2023)  | 1        | Mexico                | 6            | School in disadvantaged environment.                                                              | Grandmother with no educational background.                                 |

Table 2. Cont.

| Study                              | Method * | Country                                     | SEA **    | Context                                                                                   | Impact on the Type of Vulnerable Population Under Study                                                                            |
|------------------------------------|----------|---------------------------------------------|-----------|-------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|
| (Grau del Valle et al., 2023)      | 1        | Spain                                       | 4, 5      | School: majority of families and students of minority ethnicity.                          | Roma young and adult population in active employment.                                                                              |
| (Gairal-Casadó et al., 2019)       | 1        | Spain                                       | 4         | Institutional care centre.                                                                | Adolescents aged 12–17 from Roma and migrant population.                                                                           |
| (Garcia-Yeste et al., 2017)        | 1        | Spain                                       | 3.1       | School: majority of families and students of minority ethnicity.                          | Moroccan mothers.                                                                                                                  |
| (Álvarez-Guerrero et al., 2021)    | 1        | Spain                                       | 3.1       | COVID-19 pandemic education situation. On-line education.                                 | Secondary school students with disabilities.                                                                                       |
| (Rodríguez & Marini, 2018)         | 1        | Brazil                                      | 2, 3.1, 4 | Adult education.                                                                          | Adults with low education.                                                                                                         |
| (Díez-Palomar, 2020)               | 1        | Spain                                       | 3.2       | School for adults in the working-class neighbourhood.                                     | Adult women with basic or unfinished primary education.                                                                            |
| (López de Aguilera et al., 2023)   | 1        | Spain                                       | 3.3       | Schools from primary to adult education.                                                  | Impact on adults from low socio-economic backgrounds without higher education.                                                     |
| (A. Flecha, 2012)                  | 1        | Finland, Lithuania, Malta, Spain and the UK | 1, 6, 3.1 | Pre-schools and primary schools with students from cultural minorities.                   | Family members: illiterate adults, migrants, etc.                                                                                  |
| (Garcia-Yeste et al., 2018a)       | 1        | Spain                                       | 6         | Schools that include ethnic minorities, migrant population and low socio-economic status. | Family members from vulnerable groups including Roma, low socio-economic, and immigrant populations.                               |
| (Vieira & Miello, 2018)            | 1        | Brazil                                      | 3.1, 4    | Schools from primary to adult education.                                                  | Vulnerable adult population. Most of them drop out of school due to poverty.                                                       |
| (Odóñez & Rodríguez-Gallego, 2018) | 3        | Spain                                       | 1, 2, 6   | Pre-school and primary schools in areas of marginalisation and social disadvantage.       | Family members and adult volunteers from vulnerable groups with low socio-economic and educational backgrounds.                    |
| (Domínguez & Palomares, 2022)      | 1        | Spain                                       | 3.4       | Poor context in southern Spain.                                                           | Roma families at risk of social exclusion and with functional illiteracy.                                                          |
| (Oro & Díez-Palomar, 2018)         | 3        | Spain                                       | 2         |                                                                                           | Young people who have dropped out of school and unemployed adults with low formal education. Includes Roma and migrant population. |

(\*) Methodology: (1) qualitative, (2) quantitative, (3) mixed methods. (\*\*) SEAs: (1) community educational participation, (2) IG. (3) Types of DG: (3.1) dialogic literary gatherings (DLG), (3.2) dialogic mathematics gatherings, (3.3) dialogical musical gatherings, (3.4) dialogic artistic gatherings, (4) extending learning time, (5) DMPRC, (6) family education.

### 3.1. SEAs and Their Impact on Individual Factors

Regarding the first theme, which dealt with the analysis of the improvement of academic trajectories and skills for employment, it should be noted that it was developed in all the articles included in this study. The results showed that SEAs have a key role in training vulnerable working-age groups since, in addition to reinforcing academic training, they promote the development of skills for access to employment. The aspects most-highlighted in the studies were academic training, perseverance, development of social skills, self-esteem, teamwork, initiative, and autonomy.

The subcategory 'academic training', widely recognised as a fundamental pillar for developing employability, takes on an even more relevant role in contexts of vulnerability. SEAs impacted this area by radically involving families and the community in education. They fostered dialogic interactions and collective support, transforming students' academic and career aspirations from vulnerable backgrounds. A prominent example was the case of Roma students in the final year of secondary school, where community and family involvement and support were key to strengthening their confidence and opening previously unattainable academic horizons: 'The support students received from their families helped them to have the confidence and aspirations to think about plans that included unprecedented academic trajectories'. These experiences led to profound changes in the perception of what is possible, as expressed by one student: 'I see myself as very capable of getting to university. . . thanks to the support, above all'. In addition, the SEAs made visible and included university references in the educational spaces that shared cultural identity, becoming transformational models for their communities and promoting continuity in the studies of their young people (Natividad-Sancho et al., 2024, pp. 27, 30). This contact also strengthened academic willingness and readiness to work and fostered a greater 'valuing of performance' attitude reflecting employability.

In the case of migrant groups, IGs were shown to speed up the acquisition of the host country's language, favouring the overcoming of key educational stages for access to university (Valero et al., 2018). In this sense, DLGs were also particularly useful, as migrant women reported: 'If there is just one word we do not understand, we talk a lot about this word, we go round and round, and this is very important. I have been one year, but as if I had been 5 years' (Garcia-Yeste et al., 2017, p. 104).

Among the various SEAs, family training occupied a strategic place in improving employability, as it allowed families, together with professionals, to identify specific training needs, offer resources for their development, and guarantee their access to the exact locations where their children also study and at times compatible with family dynamics. These trainings ranged from basic literacy skills to more specific content, such as preparation for driving licences and promoting collaboration with local entities to ensure their viability (Odóñez & Rodríguez-Gallego, 2018). Vulnerable families who participated in these initiatives highlighted their impacts on training: 'I always thought about dropping out of school. . . illness in the family, work, problems. . . But I thought about the [interactive] groups, and I came. I did not miss classes, and now I will graduate' (Rodríguez & Marini, 2018, p. 10).

The subcategory of 'perseverance' has also been highlighted as a key indicator of employability. Creating spaces and interactions generated by SEAs focused on support and solidarity among peers, family members, community referents, professionals, and the rest of the community was presented as a key element to foster the commitment and effort needed to overcome obstacles and achieve joint goals. Through the community's active participation, the influence of role models with higher education who share the same cultural identity motivated us to persevere in the academic path: 'They gave us to understand that with effort, we can achieve it. . . You can still decide what to do and

how you want to do it.’ ‘[...] I doubted whether to continue studying, but I heard that and said, I want to continue studying’ (Roma students in Natividad-Sancho et al., 2024, pp. 26, 29). Collaboration, high expectations, and family education were elements that reinforced perseverance: ‘What I want is for them to study, to go to high school, to go to university and to continue studying, and I will do everything I can to make it happen’ (Mother in a school located in a high-poverty area, in (Garcia-Yeste et al., 2018b, p. 8).

The SEAs had a key role in the development of ‘stress tolerance’, another key employability skill, by fostering self-control, tolerance, emotional management, and effective conflict resolution. These actions created a learning climate in which students, regardless of their cultural background, were able to strengthen their relationships and overcome stereotypes. One adolescent migrant girl noted: ‘Through IGs, students learn from their peers from other cultures and together they create a positive, equitable and non-stereotypical climate, improving relationships among them’ (Valero et al., 2018, p. 794). An adolescent girl in institutional care described how these dynamics (DLG) transformed her environment and behaviour ‘Before, for example, if you said something to me and I did not like it. . . I would respond badly, I would get angry, I would hit you and now. . . I think about it more, and I do not hit things or anything. This same student described the coexistence before the SEAs as ‘chaotic’ (Salceda et al., 2022, p. 7), highlighting the positive change towards greater group cohesion, empathy and self-control. In work situations, as was the case of a Roma mother working in a ‘School as a Learning Community’ (SLC) who applies SEAs and who is now a reference in her community, proactive conflict resolution and stress tolerance were also highlighted: ‘You just stay (outside working hours) when there is a problem, and it has not been solved. I stay to talk to the teachers or the monitors to see how we can find a solution’ (Grau del Valle et al., 2023, p. 148). This commitment to immediate conflict resolution reinforced their sense of responsibility and contributed to more effective stress management.

The review also highlighted how SEAs foster the competence of ‘learning to learn’, a crucial skill for employability that involves a disposition towards continuous learning, the ability to adapt to new contexts, and the autonomy to make informed decisions. The SEAs had a significant impact on both students and families, promoting an optimistic mindset to take advantage of educational opportunities: ‘Interview data suggested that students, volunteers and teachers all had increased their expectations of learning’ (Zubiri-Esnaola et al., 2020, p. 173), ‘After seeing that our parents have not been able to have the privilege of studying, I want to take advantage of the opportunity’ [...] ‘Seeing that Roma people have given us examples. . . has helped us a lot to be clear about what we want to do’ (Roma pupil in her last year of secondary school, in (Natividad-Sancho et al., 2024, pp. 27–28)). The active involvement of families in their children’s education in the classroom also fostered the families’ motivation to learn and be educated (Sampé et al., 2012). Family educational support was pursued to foster an apparent change in perspective towards learning, which was internalised in the community and conveyed not only an immediate obligation but an investment for future job autonomy: ‘My father will kill me if I do not come to study. Because my father tells me: What are you doing at home without studying? What are you going to do with your life? . . . study, . . . to be someone in life is not to be an illiterate person’ (Account of a young Roma girl student about a conversation with her father, in (Girbés-Peco et al., 2015, p. 104)). The DLGs generated unprecedented motivation and results among adolescent girls in a drop-in centre: ‘Before the DLGs, the groups were not so motivated to study. Never before had all the adolescent girls in a group passed all the subjects with such good grades and expectations of going to university’ (Salceda et al., 2022, p. 8). The same result was found in the quality workshops delivered through the SEA learning time

extension (Gairal-Casadó et al., 2019), where high expectations play a key role in learning to learn competence.

SEAs, based on egalitarian dialogue and social interaction, significantly impacted the development of the subcategory of 'social skills' such as improved communication, listening, empathy and solidarity, preparing for access to the labour market and the construction of fuller lives with greater opportunities. Studies by Gómez-González et al. (2022) found improvements in communication and a greater closeness of families to the school: 'Legitimacy and respect for teachers is increased, and parents do not oppose or argue with the teacher's messages [...] Now they know how things work' (p. 107). This strengthening of the link between families and school reflected the development of social skills that transcend the educational sphere, fostering attitudes such as active listening and respect for rules. The participation in DLG of Lola, a homeless woman, evidenced the ability to understand the other point of view and act accordingly: 'The encounter makes you see things differently. You become more open to other people's opinion [...] All this has opened my mind' (Racionero, 2015, p. 922). The communicative skills acquired through collaborative learning through SEAs were also evidenced in secondary school students in special education (Álvarez-Guerrero et al., 2021).

The results showed that the support of volunteering in classroom educational activities fosters key employability competencies reflected in the subcategories of 'time management' and 'task management', as well as greater 'flexibility' in the face of change. Volunteers organised the group dynamics, managed the intervention shifts, and ensured that activities were completed on time. In a study where some of the volunteers in the English IGs were composed of immigrant parents, most of them with little academic background but with a command of English due to their origin, it was highlighted that 'The volunteer was in charge of giving instructions for the game, modelling how to play, managing the turns... asks those who understand better to help explain' (Zubiri-Esnaola et al., 2020, p. 172). Odóñez and Rodríguez-Gallego (2018) highlighted that volunteering made up of vulnerable populations demonstrated a rapid adaptation to the demands of the educational context. Similarly, it was highlighted how, in the face of unforeseen events, workers in an SLC assumed flexible responsibilities, adapting their work and schedules according to their needs (Grau del Valle et al., 2023).

The inclusion of the community in school life had a transformative effect on the people who participated, fostering their 'initiative and autonomy', which led them to lead processes of change. Oro and Díez-Palomar (2018) relate:

'At the beginning of the course, I had to urge the participants to help each other [...], but after a few sessions, they were already standing up for themselves as soon as they saw that one of their classmates was having difficulties [...] Sharing and learning around IG from a practical and theoretical level has empowered the same participants who have led the SEAs in their classes, leading the change process themselves'. (p. 60, 68)

This leadership also extended to collective decision-making in spaces such as the mixed commissions (within the DMPPRC), where key issues are discussed and decided upon, as was the case with the implementation of new educational stages in a neighbourhood with deep social inequality: 'The educational participation of the community in the La Paz school had led families, teachers and educational leaders to opt for the implementation of secondary education in the center' and 'In 2012, the importance of educational participation was again manifested through another key decision (of the community): to incorporate a school for adults in the same educational center' (Girbés-Peco et al., 2015, p. 104). This strengthening of autonomy and initiative also manifested in even more adverse contexts. In a longitudinal study in a prison, DLGs became spaces for freedom

and reflection. Through dialogue, participants could project new possibilities for their future and move forward to achieve them upon release, overcoming barriers of social exclusion, reinventing and taking control of their lives to transform their personal and social trajectories (R. Flecha et al., 2012).

The subcategory of ‘self-esteem’, recognised as a key factor for employability, was strengthened through high educational and social expectations promoted through dialogic and community actions. For example, implementing Dialogical Mathematics Gatherings strengthened participants’ self-concept, especially among those facing initial educational barriers (Díez-Palomar, 2020). Including cultural diversity in heterogeneous educational spaces also significantly fostered solidarity and mutual respect, increasing self-esteem in immigrant adolescents (Valero et al., 2018). Furthermore, the sense of belonging generated by supportive communities played a central role. In the mental health field, Zubiri-Esnaola et al. (2023) documented how patients who participated in DLG in a Spanish hospital experienced personal empowerment that allowed them to actively project themselves towards transforming their reality. Similarly, Garcia-Yeste et al. (2017) highlighted how migrant mothers from impoverished contexts who participated in DLG were able to develop both language skills and greater confidence to face everyday challenges, strengthening their identity. In addition, international experiences confirmed that educational environments based on respect and dialogue promote self-esteem while fostering learning. In a school in Brazil, with a high percentage of adults who had dropped out of school due to poverty, Vieira and Miello (2018) showed that learning in a supportive and dialogical context contributed decisively to strengthening the self-concept and confidence of their participants.

SEAs also strengthened essential ‘personal and emotional care’ skills, indispensable for accessing new job opportunities and building a dignified life. Based on participation in DLG, this factor was shown in the adult population with mental illness and the prison population. The study by Zubiri-Esnaola et al. (2023) with adults with mental illness revealed that key improvements in their rehabilitation processes were linked to their participation in DLG dialogues inspired by episodes from classical world literature (p. 876). Meanwhile, the study by R. Flecha et al. (2012) highlighted testimonies such as: ‘They provided me with an important emotional situation: feeling a little less imprisoned’ (p. 155). Among socially excluded women, the impact of SEAs also translated into a revitalization of personal and emotional care. Racionero (2015) reports the testimony of a homeless woman who describes how the DLGs transformed her routine: ‘Before I would stay at home saying to myself “I do not feel like going out of the house”, I would get depressed, and now... coming here all that disappears. I feel very good, very liberated’ (p. 924). On the other hand, in Roma communities, SEAs fostered a sense of belonging that goes hand in hand with increased self-esteem, an aspect highlighted by Grau del Valle et al. (2023). Similarly, in immigrant mothers, the DLGs generated concrete impacts on their ability to relate to health and social services, as noted by Garcia-Yeste et al. (2017):

One of the women describes how she overcame a barrier when she went to health services. Prior to her attendance at the talks, she found it very difficult to relate to professionals. Now, this situation has changed, and she can explain very well what is happening to her and her children. (p. 104)

In family training, transformations in self-care and self-perception were also evident. Garcia-Yeste et al. (2018b) narrate how one participant, initially forced to attend by social services, experienced a radical change:

Belén two years ago, came with slippers, pyjamas, and so on, little hygiene [...] until she signed up for family training. We started to see a change, she was more dressed up, but above all, what we noticed was a different look—not only how

her son looked at her, but also how she looked at itself now. That transformation was very striking. (p. 56)

In addition, SEAs can also significantly contribute to and accelerate the development of 'digital competencies', which are essential for employability in an increasingly technological world. In school dropouts and unemployed adults with little education, including Roma and migrants, participation in IGs facilitated the acquisition of digital skills more quickly and confidently, thanks to their collaborative dynamics (Pacto Mundial de las Naciones Unidas. Red Española, n.d.).

Family involvement in the school and the networks generated between teachers and families also increased the 'work experience' subcategory of vulnerable groups, a key factor for employability. Francisco showed a remarkable commitment to the school, and the teachers encouraged him to enrol in a formal vocational school. After graduating, the school offered him a contract as a mediator to increase the participation of the Roma community (Gómez-González et al., 2022), which allowed him to gain valuable work experience within an educational environment. Also, in a very poor neighbourhood, the active involvement of the neighbourhood in their children's school enabled them to access academic training and, in turn, work experience. One Roma neighbour expressed:

I have been able to be what I am now, which for me (. . .) is a lot because through these courses I can work in the summer schools, the three summer months I always work, and I have worked three years in the school canteen here. (Girbés-Peco et al., 2015, p. 105)

The impact of SEAs, such as IGs, documented the improvement of 'teamwork'. In immigrant secondary and high school students, Valero et al. (2018) noted that 'IGs facilitate bonds of solidarity and mutual support among peers, thus promoting a positive climate of cooperation and coexistence' (p. 794). According to Oro and Díez-Palomar (2018), implementing IGs allowed members from vulnerable contexts to develop teamwork skills through dynamics that promote active adulthood and social inclusion through intergenerational and intercultural dialogue, generating significant learning in group contexts. In the framework of the DMPRC, a study with students aged 14 to 16 in Colombia (Sánchez, 2018) showed how the dialogic gatherings transformed school coexistence. The students drew up pedagogical accords that were agreed upon and evaluated by themselves, significantly reducing disciplinary conflicts and strengthening collaborative work. On the other hand, Garcia-Yeste et al. (2018b) describe how family education and DLGs among vulnerable minority mothers facilitated instrumental learning and strengthened trust and mutual support between families. These interactions helped families work together, share their problems and strategies to overcome them, and foster community mentoring and peer support, increasing social cohesion and collaborative skills in school and neighbourhood communities. Similarly, Vieira and Miello (2018) highlighted that learning more egalitarian dialogue based on respect and active listening strengthened teamwork skills in vulnerable populations who dropped out of school due to poverty. This impact was also observed in secondary school students with disabilities, where Álvarez-Guerrero et al. (2021) identified improvements in attention, behaviour and ability to collaborate after implementing online DLGs. Finally, Sampé et al. (2012) and Valls-Carol et al. (2014) highlighted that the involvement of vulnerable families in schools, promoting their active participation, improved coexistence and motivated both families and the school community to work together, thus reinforcing teamwork skills.

### 3.2. Influence of SEAs on the Personal Circumstances Factor

Regarding the second theme, SEAs had a profound and transformative impact on participants' circumstances (circumstantial factors), generating changes beyond improving

their individual skills to increase employability. Although all the studies reported changes, half highlighted this aspect more explicitly. The studies particularly highlighted the creation of quality relationships, the establishment of friendship and support networks, and the generation of social capital, which significantly enhanced the personal and social well-being of the participants. The review also identified that these experiences fostered a culture of collaboration and effort that fed back into healthy social environments, collaborative and problem-solving networks, and improved interaction with other resources.

A clear example of this impact was observed in the Moroccan women participants in DLG, who, by sharing their experiences, were able to empathise with the situation of loneliness experienced in Spain and opened new spaces for interaction, thus creating relationships that promoted a healthier and more enriching social environment (Garcia-Yeste et al., 2017). In De Botton et al.'s (2014) study, the women participating in the DLGs barely knew each other and limited themselves to a formal greeting. However, the new relationships that emerged helped strengthen true friendships over time. This type of bonding benefited these women and positively impacted people with mental health problems, who, according to Zubiri-Esnaola et al. (2023), emphasised the importance of weaving networks of relationships that help them cope with life's difficulties. Identifying these networks becomes crucial in changing personal circumstances, moving from isolation to empowerment, where support drives change.

On the other hand, family literacy programmes, such as those described by Ocampo-Castillo et al. (2023), demonstrated how literacy improves educational skills and facilitates access to social capital. A telling example was that of Maria, who, despite never having attended school, managed to overcome her fear and shame thanks to the support of her granddaughter, with access to the programme being facilitated by taking into consideration her circumstances. This story transformed her life and allowed her to become a role model within her community, generating social capital that benefits other women. The creation of referents was also observed in programmes aimed at vulnerable families, where parents improved their skills and became role models for their children. As Dina, a mother, mentioned: 'I am an example for them [my children]; if I have achieved it, they can achieve it' (Garcia-Yeste et al., 2018b, p. 7). This type of social capital facilitates access to more information about the environment. It strengthens a culture of effort that can impact the community's future, favouring their access to the labour market.

In addition, SEAs showed the fostering of a participatory culture that promotes solidarity and the creation of support networks both among participants and professionals as well as with involved entities, which facilitates access to information and better interaction with surrounding resources. In the study by Garcia-Yeste et al. (2017), one of the women participating in DLG reported overcoming barriers to accessing health services. The same study also highlighted how these experiences strengthened family relationships and bonds of solidarity. One mother expressed in another study: 'There is good companionship, we get along well, we share everything, we help each other' (Garcia-Yeste et al., 2018a, p. 55). At the same time, the participation promoted by SEAs in schools (decisive, evaluative, and educational participation) favoured the personal and collective promotion of the community and greater social involvement beyond the educational centres, which has a positive impact on people's quality of life (Valls-Carol et al., 2014).

### *3.3. Impact of SEAs on Contextual Factors*

Regarding the third and last theme, the social transformative power of SEAs offered fundamental keys for the design of social, educational, and employment policies. All the articles provided key contextual aspects for forming the employability of vulnerable groups, emphasising the creation of inclusive and supportive environments. In addition,

the development of capacities that facilitate active participation in the community was highlighted (e.g., mixed commissions in Ramírez & Marín, 2022), where co-creation played an essential role in ensuring the effectiveness of these processes.

SEAs ensured a favourable context for training to be accessible to families for two fundamental reasons: they were carried out in the same school spaces where their children were studying, which allowed familiarity, proximity and easy access, and they also encouraged the co-creation of training interventions with professionals. This approach ensured that activities responded directly to the specific needs and aspirations of families and the educational community (Flecha, 2012; Garcia-Yeste et al., 2018a, 2018b; Gómez-González et al., 2022; Ocampo-Castillo et al., 2023; Odóñez & Rodríguez-Gallego, 2018; Sampé et al., 2012; Vieites et al., 2021).

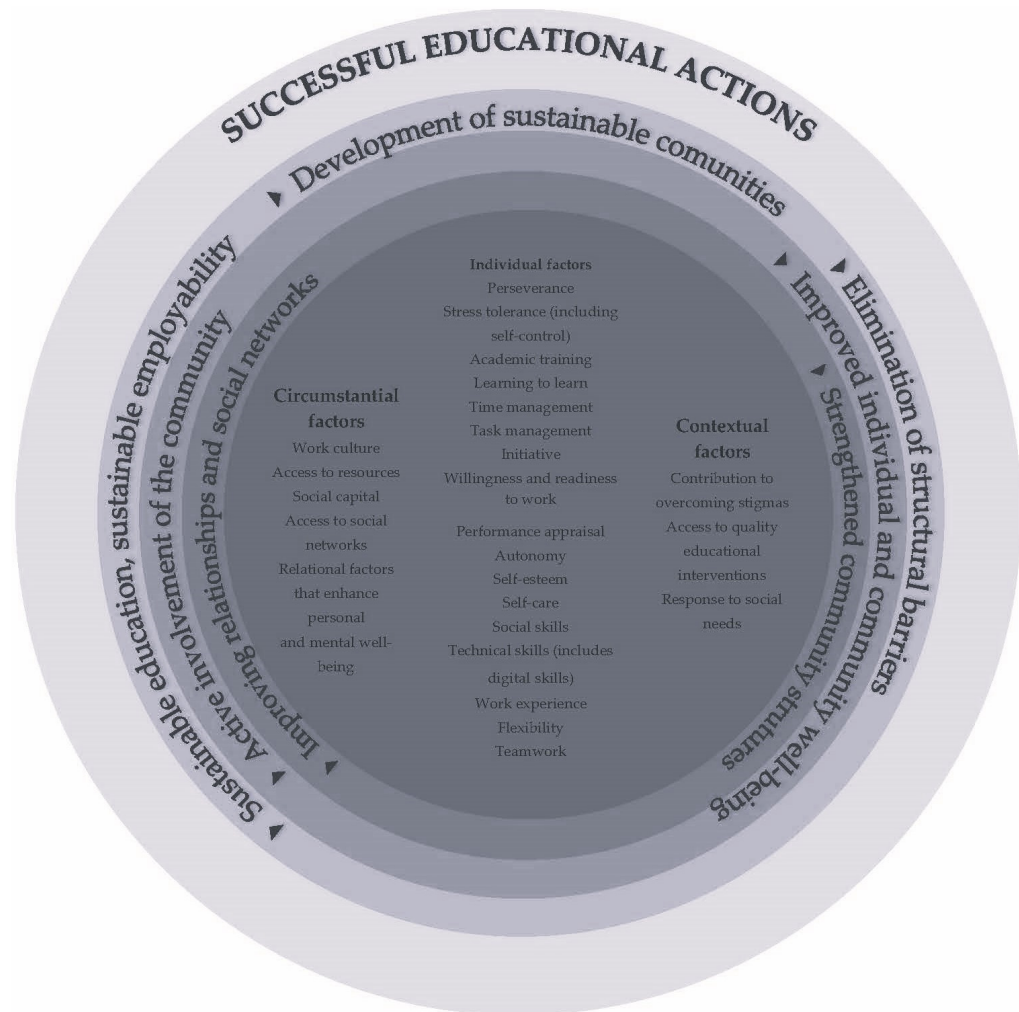
Another important contextual factor that transcends the school setting and positively affects society at large is SEAs' contribution to overcoming stigma and stereotypes (Valero et al., 2018). DLG empowered migrant women by breaking down stigmas of gender and ethnicity, which strengthened their social inclusion (Garcia-Yeste et al., 2017). By overcoming barriers in their communities, these women enhanced the transformative effect of these interventions.

Access to quality educational interventions is another crucial factor in transforming the social and labour context. Oro and Díez-Palomar (2018) found that even short programmes can generate and accelerate significant progress in digital skills, facilitating the labour market integration of people at risk of social exclusion. These interventions directly benefited the people who participated and strengthened community structures, promoting more sustainable environments. It was also evident in the studies by Gairal-Casadó et al. (2019), who highlighted how quality actions (scientific workshops within SEAs to extend learning times) with adolescents in institutionalised situations not only compensated for the lack of family support by providing tools for learning and improving future opportunities, but also extended their impact to strengthening vulnerable communities.

Moreover, SEAs have proven to be an effective tool to inform and guide the development of inclusive public policies. The experience of the ETPI programme (which in Portuguese refers to the Educational Territories of Priority Intervention) in Portugal (Vieites et al., 2021) illustrated how these actions can be integrated into national policies, benefiting many students and their families. This project, piloted in priority intervention territories, was expanded after successful results, demonstrating how a multidirectional dialogue between schools, researchers, governments, families and other community actors can facilitate implementing and scaling up sustainable intervention models.

At a general level, the results showed that participation in SEAs boosted employability in their three broad dimensions: individual factors, circumstantial factors, and contextual factors, with a particular emphasis on learning of high expectations, relationships, and community participation, key elements underpinning the conceptual framework adopted to analyse this impact. The thematic analysis of these three categories is presented in Figure 2.

The results confirm the strong interrelationship between individual, personal, and contextual factors. Their holistic approach based on SEAs contributes to the development of a more sustainable employability model for vulnerable populations, combats social and employment inequalities, and proposes a framework for more sustainable interventions.



**Figure 2.** The main findings of the study. Note: own elaboration.

#### 4. Discussion

School inequalities are a global concern. They generate social and labour inequalities. In the Spanish context, characterised by its diversity and multiculturalism, these inequalities are especially evident in immigrant students, cultural minorities, those from disadvantaged backgrounds, and students with disabilities or greater educational support needs. ESAs have demonstrated their effectiveness in inclusion and in reducing inequalities in these groups. Although there are systematic reviews that have analysed their impact on primary school students (Morlà-Folch et al., 2022) and adolescents (Natividad-Sancho et al., 2024), no explicit systematisation of their contribution to the development of employability has been found. In this context, the aim of our study was to analyse the impact of SEAs on the employability of vulnerable working-age groups. Our research question was: Does the impact of ESAs encompass the three main dimensions that influence employability (individual, circumstantial, and contextual factors), thus contributing to the reduction in social and labour inequalities through a sustainable intervention?

This systematic review addressed one of the major international concerns: a sustainable, inclusive, and quality education that guarantees the demands of the labour market and reverses unemployment, poverty and social exclusion. In this way, it contributes to the United Nations Sustainable Development Goals (SDGs) 1, 3, 4, 8, and 11 (ONU, n.d.).

In general, international agencies emphasise in their agendas the need to improve the job prospects and quality of employment for disadvantaged people. To achieve this, they advocate inclusive education and training systems that respond to the diversity of

needs of vulnerable groups (Pacto Mundial de las Naciones Unidas. Red Española, n.d.). These systems must identify and overcome barriers, be flexible to meet diverse individual and contextual needs, provide support services through training, promote labour rights and safety, address prejudices and social stigmas, and improve the status of these groups (OIL, n.d.). However, much remains to be done, as the goal is still relevant today. In this sense, SEAs are fundamental as they have demonstrated their capacity to generate educational and social transformations; this study analysed their role in developing transversal employability competencies individual factors. SEAs develop key transversal competencies for a changing labour market. Secondly, the results of this study underline the transformative role of SEAs in enhancing employability because they included three main factors: individual factors, circumstantial factors, and contextual factors. This impact is underpinned by sustainable education, emphasising learning with high expectations and the importance of relationships and dialogic community engagement as key elements. These dimensions underpin the conceptual framework adopted, respond to our research questions, and emerge as fundamental pillars for addressing educational and occupational inequalities. Social interaction based on reflection from egalitarian dialogue, solidarity and the establishment of quality relationships between students, families, education professionals, and the rest of the educational community are drivers of change. These interactions strengthen key competencies, mobilise resources, and build environments that transcend the limits of the school, becoming spaces for labour inclusion. Therefore, SEAs are key tools for fostering sustainability by facilitating labour market insertion, promoting more effective adaptation to social needs and market demands and, consequently, supporting long-term socio-occupational development.

From this transformative perspective, it is crucial to specify how these dynamics are linked to the employability of vulnerable groups. First, in line with previous studies that highlight academic training as a key factor and essential filter for access to employment (Formichella & London, 2013), the findings of this review highlighted that SEAs are presented as a fundamental complement within educational systems and programmes. In addition to strengthening academic training, SEAs played a crucial role in the development of other key competencies, such as perseverance, stress tolerance, self-esteem, social and technical skills, learning to learn, time and task management, willingness and readiness to work, performance appraisal, flexibility, teamwork, self-care, and work experience, competences identified in the international literature as transversal for the development of employability (González-Navarro et al., 2023). These competencies, fundamental for labour market insertion, were strengthened through dynamics that promote high academic and social expectations, egalitarian interactions, dialogue, and mutual support, allowing participants to overcome obstacles and develop a more significant commitment to their learning and professional development.

Second, the results showed that SEAs strengthened the individual factors previously highlighted and generated significant transformations in circumstantial factors, promoting stronger personal well-being. The social support networks that emerge through these actions, such as collaboration, problem-solving, safety, or friendship, are aligned with the relational well-being model proposed by Cottam (2011). This model highlights the importance of relationships in solving problems and facilitating a process of discovery and transformation, in which professional figures and support persons do not intervene directly but listen, challenge, and support this process.

According to Cottam (2018), when people receive the proper support and build meaningful connections, they acquire the necessary tools to change their personal circumstances and transform their social realities. He further emphasises that capacities must be developed locally, with relevant support (Cottam, 2011). Relationships within families, between

families and the team, and with broader social connections are key to generating sustainable change. Similarly, Pearson et al. (Pearson et al., 2023) and their relational employability approach highlighted that employability depends on acquiring skills and building social and community support networks that enable individuals to make informed choices and overcome social barriers. In this sense, SEAs support coping with everyday difficulties and foster relational employability by promoting collaboration and solidarity. Participants can receive support and, at the same time, contribute to the common good, either through volunteering or by participating in collective decision-making processes, such as the joint commissions within the DMPCR. This shared approach reinforces a sense of belonging and social responsibility, building strong bonds that foster trust and quality relationships, helping to overcome situations of isolation and exclusion.

Along these lines, Waldinger and Schulz (2023) highlighted that the brain responds positively to contact with others. They noted that positive interactions signal security, reducing physical arousal and increasing well-being. Thus, social connections keep us happier and healthier and reinforce the importance of quality human relationships, such as friendship, which ensure holistic, healthy, and positive cognitive and emotional development, not only for the individual but also for humanity (Racionero-Plaza, 2017).

Following Cottam's (2011) vision, this transformation process moves away from blame culture and towards creating new connections and networks, which, in turn, can open doors to new jobs, interests, and support. With SEAs, this process was also enriched by the visibility of positive referents, socialisation into a culture of effort, collaboration and leadership, and overcoming barriers to accessing other environmental resources, improving people's quality of life. Therefore, this holistic approach strengthens social capital, enhances empowerment, and builds resilience, significantly impacting individuals and their families and communities, transforming them into more inclusive, supportive, and sustainable environments.

Furthermore, the results showed that contextual factors emerged as central to the transformative impact of SEAs. The distinctive creation of more inclusive and equitable environments through SEAs can serve as a guide to ensure that any inclusion-oriented policy is effective. It is essential to establish an enabling context that supports these transformative processes. SEAs have proven crucial in facilitating access to quality educational interventions, overcoming stigma and stereotypes, and promoting dynamics that transform exclusionary practises, generating more supportive, participatory, and transformative environments.

From the capabilities approach proposed by Amartya Sen (2000), creating contexts that enable these changes is essential. Without these appropriate environments, people will not only lack the possibilities to thrive, but even if they have the potential, they will not have the capabilities to achieve it. A key transformative element is a co-creation process, which facilitates the construction of responses aligned to the real needs of the social context, linking bottom-up movements (Gómez-Cuevas & Valls-Carol, 2022; Vieites et al., 2021). Lindsay et al. (2019) indicated that accompaniment strategies are more effective when co-produced with users, as they take advantage of their assets, resources, and capacities for action, responding precisely to their needs and aspirations.

In this regard, Pearson et al. (2023) highlighted that peer-based support and co-creation of pathways to employability are positively valued, foster self-efficacy, and mitigate social isolation, reinforcing the transformative impact of these interventions. This approach provides a sense of control, empowerment, and belonging, aspects that coincide with the findings of this study, highlighting the importance of relational interactions in the creation of support networks and the transformation of personal and community circumstances. SEAs promoted people's active participation in their change and improvement processes,

integrally involving families, professionals, local agents, and volunteers, consolidating participatory processes that promote inclusion and equity.

This dynamic connects with the principles of Freire's (1997) pedagogy of the oppressed, who argues that people, by achieving 'conscientisation', not only recognise social inequalities but also become empowered to transform and fight against them. In this context, the principles of dialogical learning (Aubert et al., 2008) made it possible for students, volunteers, and the rest of the community to actively participate in this 'conscientisation' through the actions and mechanisms of collective reflection and deliberation promoted by SEAs. Spaces such as mixed commissions allow participants, together with professional figures, to analyse their circumstances critically, reflect on the structural causes of the inequalities they face, and generate joint proposals to overcome them (Ramírez & Marín, 2022). This process strengthens individual action and leadership and fosters a commitment to the common good, mobilising local resources and strengthening community networks. SEAs' radical commitment to volunteering and collective participation generates dynamics that transform the social fabric and consolidate sustainable development in the most vulnerable communities, promoting equity and social cohesion. Finally, the sustainability of these actions lies in their capacity to transform educational and social contexts, making them an effective strategy for combating structural inequalities. Their scalability and adaptability, together with the active and distinctive participation of all the people and groups involved (Vieites et al., 2021), consolidated SEAs as a viable tool for generating changes and building a fairer and more equitable future that enhances the employability of the most vulnerable people. As opposed to traditional interventions, which tend to prioritise employment without considering circumstantial and contextual factors that affect the most vulnerable groups, SEAs focus on overcoming these structural barriers. This comprehensive approach allows people in vulnerable situations to increase their individual competencies, in terms of academic and professional training, with a view to obtaining employment, and can also be sustainable because they alleviate personal and contextual circumstances to address the inequalities that originally limited their employability.

These actions, following Pearson et al. (2023) who criticised interventions and policies that prioritise entry into employment in the process of socio-labour integration, not only benefit people individually but also strengthen relationships and social networks, as well as foster community support and decision-making structures. This enables people not only to receive support but also to play an active role in their environment, improving both their well-being and quality of life and that of their community. In this way, they actively contribute to combating inequalities and building more inclusive and sustainable communities.

The results concluded that the high social and educational expectations, quality relationships, active participation, community engagement, and co-creation promoted by SEAs generate substantial capital with a significant impact on employability. These factors foster participants' personal and social well-being and contribute to building more sustainable cities and more inclusive and lasting employability. Moreover, as the literature shows, SEAs are transferable to different contexts (R. Flecha, 2015), making them an applicable tool for interventions that increase the employability of vulnerable working-age groups, such as socio-occupational insertion pathways.

In this sense, training in SEA for education professionals (e.g., social education, pedagogy, social work, teachers and school management) is essential to generate real changes in the lives of the most vulnerable people. Studies have already demonstrated successful outcomes with university students participating in SEAs (e.g., Amber-Montes et al., 2024; Foncillas & Laorden, 2014). These findings highlight the importance of extending this approach to future professionals who will play a key role in socio-occupational integration.

It is fundamental not only to affirm that the person must be the protagonist of his or her transformation process, as opposed to conceptions of employability that reduce access to any job without considering its impact on quality of life or its meaning for those living in vulnerable situations, but also to identify the keys to achieve it. It implies that both the professional figures and the people themselves perceive and live this protagonism as a central element in the transformation process.

It is a matter of co-creating personalised itineraries and designing solutions with the essence of community support from citizens and the backing of science, hand in hand with professional figures. Based on co-creation, this approach promotes the person's active and effective participation, reinforcing their responsibility, motivation, and commitment in their labour market insertion process.

In this context, these findings underlined the need to implement and expand these actions through public policies, consolidating SEAs as a sustainable and transformative strategy capable of redefining employability trajectories marked by social exclusion towards decent, sustainable opportunities that facilitate social mobility. Thus, this study has systematised the impact of SEAs on the development of employability of vulnerable working-age groups. However, it should be noted that this work has some limitations, which, although they do not affect the validity of the findings, open opportunities for future research. For example, a specific search was not carried out for each of the seven types of SEA, nor were the bibliographical references of the selected articles explored, a strategy that could have enriched the results by identifying additional studies (Whittemore & Knafl, 2005). Furthermore, the search equations used, although well-founded, may not have covered the totality of relevant studies due to variations in titles or keywords used by different authors. Future research could address these issues by broadening the databases consulted, deepening the bibliographic references and designing specific searches by type of SEA, which would contribute to a more comprehensive understanding of their impact. In addition, we have used the Critical Appraisal Skills Programme (2024) method to analyse the quality of evidence of the articles; however, there are other methods that could also be used, for example, GRADE (Aguayo-Albasini et al., 2014). Finally, we would also like to highlight that, as a search criterion, we have used the inclusion of SEAs only identified in INCLUD-ED. Future research should consider including all articles describing SEAs, even those not identified by the INCLUD-ED project, if they meet the established criteria. This would broaden the evidence base and ensure a more comprehensive and representative analysis of the available data.

## 5. Conclusions

The aim of this study was to analyse SEAs as guarantors of educational sustainability, with a focus on their impact on the development of employability of vulnerable working-age groups. The findings confirm that SEAs were found to develop key transversal competences to adapt to a dynamic and constantly changing labour market. Furthermore, SEAs were shown to have a transformative role in enhancing employability by addressing individual factors, personal circumstances, and contextual factors. Moreover, SEAs are key tools for fostering sustainability by facilitating labour market entry, promoting more effective adaptation to social needs and market demands, and consequently supporting long-term socio-occupational development. Therefore, the most significant contribution of this work is its comprehensive approach that encompasses the entire community. This holistic approach allows SEAs to be guarantors of educational sustainability. This highlights the development of more sustainable employability of the most vulnerable working-age group.

These findings highlight the importance of SEAs in moving towards inclusive, quality, and sustainable education, aligned with the development of sustainable employability. The

skills and relationships promoted by SEAs foster social justice and overcoming inequalities, thus contributing to community sustainability.

From a practical perspective, it is essential to incorporate educational and socio-occupational strategies that integrate SEAs as transformative tools, ensuring relevant interventions and adequate support to improve the employability of vulnerable groups. Furthermore, education policies should prioritise relational approaches that strengthen dialogical participation and meaningful connections between students, families, education professionals, and researchers, promoting co-creation processes that provide solutions to the diversity of contexts by jointly recreating the evidence that science has already shown to have a social impact. In this way, these actions transform individual realities and enhance far-reaching social sustainability.

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## Article

# Educating Future Agricultural Engineers at the University of Burgos, Spain, through a Service-Learning Project on Rural Depopulation and Its Social Consequences

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**Abstract:** A Service-Learning Project (S-LP) is a teaching experience through which the concepts covered during an educational course can practically be applied to address a given social problem. It is therefore a useful teaching methodology to bring courses closer to the real world. An S-LP experience is reported in this paper that was conducted with students of agricultural engineering to address the problem of rural depopulation, through the design of agri-food buildings for industries, and economic activities that help to maintain a stable population. After the S-LP, a survey was administered to both students and teachers, to assess the success of this teaching experience. The responses of the students showed not only an awareness of the social problem that was addressed, but also a critical spirit that led them to seek the best possible answer, and a global vision of the issue. It helped them to reflect on all of its facets to arrive at a way of engaging with the social problem. Importantly, the students were able to reflect upon how engineers can also serve society through their technical knowledge. The teachers indicated that the S-LP motivated the students on the course, while enabling them to successfully learn the concepts, and to develop independent study skills searching for information. In general, an S-LP is an experience that the teachers in this study would recommend and that could be especially relevant for universities assuming a role as a social entity to heighten the visibility of social problems and needs.

**Keywords:** agricultural engineering; agri-food building; depopulation; qualitative analysis; reflection activity; rural environment; service-learning project; social service; university teaching; word-cloud mixed analysis



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## 1. Introduction

In the past, traditional university teaching was lecture-based. In the lecture hall, the teacher would explain the theoretical and/or practical concepts of the course to the students, who were passive listeners and note takers [1]. Student participation was limited to asking any doubts, if they considered it necessary, during the class [2]. However, in recent years, new methodologies have emerged with the purpose of involving students in their learning and showing the direct application of the aspects covered in class [3,4]. Outstanding examples of new teaching methodologies that seek to foster an active learning attitude among students include the flipped classroom, in which students must make a first approach to the concepts before the class in which they will be addressed [3,5]; collaborative learning, where students are encouraged to explain the concepts to each other [4]; and formative peer evaluation, where students correct the assignments of their classmates, give them feedback, and conduct an evaluation that is not counted for a grade [6]. The direct application of the aspects dealt with in class is achieved through

techniques such as virtual or on-site visits [7], and educational strategies such as a Service-Learning Project (S-LP).

An S-LP consists of a project or assignment related to the content of the course through which a direct service is provided to society [8]. In other words, it is a teaching activity through which the concepts studied in class are applied and, at the same time, offers a way of engaging with a social need [9]. The first experiences with S-LP date back to the last quarter of the 20th century [10,11], and they have been evolving ever since then [12,13]. Studies have shown that, through S-LP, students not only learn the concepts of the course, but they also learn how to apply them, demonstrating the social utility of one profession or another [14]. Furthermore, through S-LP experiences, students can develop skills such as effective communication, critical analysis, and professional ethics [15]. However, S-LP experiences also mean that society can learn, i.e., people whose needs are addressed can learn how certain issues can be tackled. It is therefore not only a question of student learning, but it is also a way for society to find paths through which they could engage with existing social problems [16]. Finally, it is a methodology that brings together the academic and social fields, promoting beneficial collaboration [17].

A teaching methodology based on S-LP experiences is valid for any field. Law and medicine are typical examples for this type of teaching experience [18,19], due to the widespread perception in society that these professions offer a direct service to society [19]. The performance of S-LP approaches within engineering is scarcer [17], perhaps because there is no widespread perception in society of the social service of engineering, although the social work of engineers is very broad [20,21]. For example, a civil engineer designs infrastructures for transportation and water supply, among others. A building engineer develops buildings to provide housing. And an agricultural engineer designs crops to provide food and infrastructures that develop the rural environment and improve rural living conditions. This perception is also not helped by the high number of concepts that have to be explained on technical university courses [22], generally of a very varied nature that are hardly conducive to focusing this type of activity on a specific social issue [23,24].

As indicated in other studies, only 8.5% of the studies published on S-LP in indexed journals are related to engineering [25]. If we look for studies that include the terms “service-learning” and “agricultural engineer” or “agricultural engineering”, they are almost non-existent. Within this field, the S-LP experiences developed by The Ohio State University stand out [26–28], which have allowed, among other aspects, the improvement of energy and water supply in agricultural plantations in Honduras [28]. Some S-LP experiences have also been developed in the field of thermodynamic agricultural engineering, in which it was concluded that this teaching methodology has improved the motivation and retention of concepts among students [29]. However, the number of S-LP experiences related to agricultural engineering is very low and, as indicated above, agricultural engineering is of immense social utility, so further projects could reinforce this teaching methodology [30].

In this paper, an S-LP experience is reported that formed part of the Bachelor’s Degree in Agroalimentary Engineering & the Rural Environment, at the University of Burgos, Spain. The objective of the project was, through the development of agri-food buildings, to try to mitigate the depopulation of rural areas and their low populations within the interior of Spain [31], among which is the province of Burgos that was also the geographical area of the S-LP. In this study, the S-LP and the projects that the students developed are described, after which the opinions of both the students and the teachers who implemented the project are analyzed in depth. The aim is to show that this type of teaching experience is useful for learning in the field of agricultural engineering, as well as enriching students at a personal level, allowing them to become aware of the social problems that can be addressed through their technical training and how they can contribute to that aim.

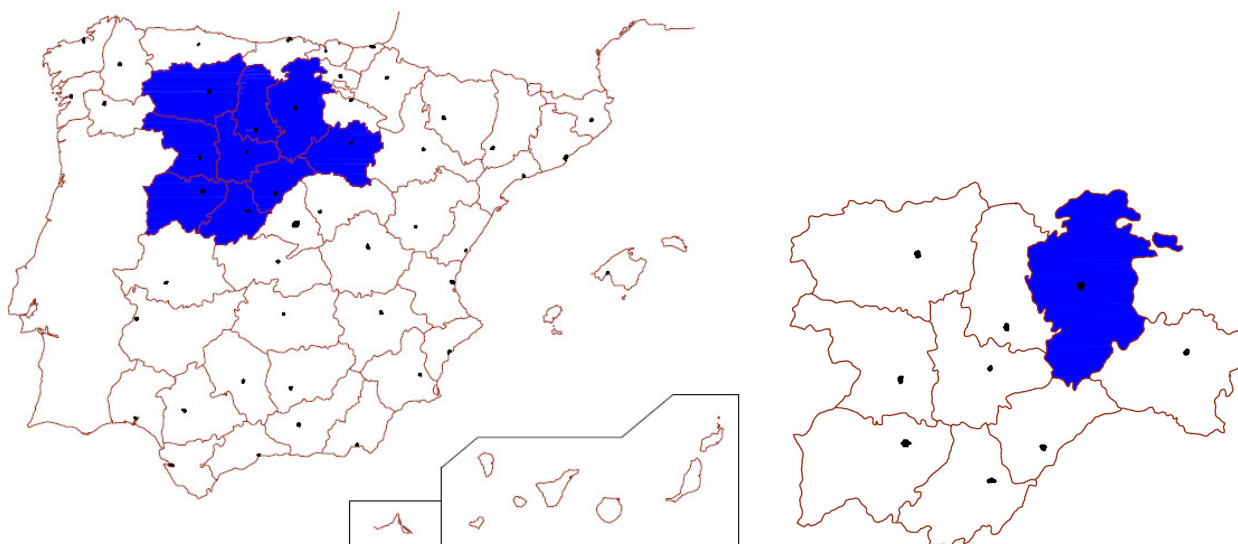
## 2. Description of the Service-Learning Project

### 2.1. Social Problem Addressed: Rural Depopulation

According to the latest available data from the Spanish Ministry of Agriculture, Fisheries and Food [32], the population living in rural areas of Spain, considering municipalities with fewer than 30,000 inhabitants and areas with population densities below 100 inhabitants per km<sup>2</sup>, is 7,538,929 inhabitants, which represents only 15.9% of the total population of Spain. This percentage is very low, as the rural environment in Spain represents 84.2% of the land mass. Moreover, the population is ageing fast. In the urban environment, 14.8% of the population is under 15 years old, while only 12.3% of the rural population is under 15 years old. On the other hand, 23.9% of the rural population is over 65 years old, while that percentage in the cities is 18.6%.

These figures are worrying, but they are even more so if their evolution over time is analyzed, and it is a fact that the population living in rural areas in Spain has been progressively decreasing over the years. For example, the population in rural areas has decreased by 7.1% over the decade from 2011 to 2020, despite the fact that population growth stands at 0.6% in Spain [32]. Besides, it leads to an increase in the average age of the population within the rural environment, with a clear tendency for young people to migrate to the cities [31]. It is widely recognized that not preventing the movement of young population away from rural environments is problematic, as it affects different professions such as agriculture, livestock, and various industries that are fundamental in the economic and social functioning of the country, and to successfully achieve so-called “sustainable development” [33]. Such is the scale of the problem that an organization called “España Vacía” [Emptied Spain] has even been launched to work towards the recovery of these rural areas [34].

It is also evident that not all areas of Spain present this problem. Coastal areas and large cities are more densely populated, and the problem of depopulation is found mainly in the interior of Spain [33]. Castilla y León, for example, is a region located in the north of Spain, where the rural population has decreased by 14.3% between 2000 and 2020 [32]. The province of Burgos, the spatial framework for the study of the S-LP, is located within that region, as shown in Figure 1.



**Figure 1.** Location of Castilla y León (left) and the province of Burgos (right) within Spain.

In view of the above, the S-LP under study was intended to address the problem of depopulation in rural areas of the province of Burgos, Spain, adopting the activation of the economy as a point of action. Thus, the aim was for future agricultural engineers to address the creation of farms and agri-food processing industries, through the design of agri-food buildings in places with potential for exploitation and commercialization. This

activity would help to sustainably fix the population within the rural environment, creating new workplaces [34].

It is important to note that the approach of the S-LP was only hypothetical, looking for students to find social utility in the design of agri-food buildings that would motivate their learning and involvement in the course, and their sense of social service. This hypothetical approach of an S-LP has been used in different studies regarding this type of teaching activity in the engineering field, including agricultural engineering, due to the economic resources necessary for the implementation of the solutions proposed through the S-LP [25,29]. Therefore, economic investment for the construction of the agri-food buildings was clearly beyond the teaching approach reported in this study.

## 2.2. Participants and Courses

The S-LP addressed in this study formed part of the Construction & Agroalimentary Building course in the third year, second semester, of the Bachelor's Degree in Agroalimentary Engineering & the Rural Environment at the University of Burgos, Spain. A total of 10 students participated in this S-LP, with an average age of  $21 \pm 1$  years. The reduced group of participating students allowed them to be actively involved in all the activities of the project. The S-LP was developed by the two teachers in charge of teaching the part of the course on agri-food building design, whose average age was  $35 \pm 11$  years old.

## 2.3. Service-Learning Project Approach

An approach of problem-based learning was adopted in the design of the teaching activity [35], as can be noted in the stages and reflection activities shown in this section. However, this teaching activity would also have service outcomes, also listed below, thus approaching it as an S-LP [25]. This classification as an S-LP was possible by understanding this type of teaching activity in a broad approach, since *“service-learning can also be defined as a form of education that matches a tangible need in a community with students participating in a learning experience”* [9].

### 2.3.1. Stages of the Project and Activities Conducted

The S-LP consisted of the following stages, labelled with the letter *S*, in order to address both the design of the agri-food buildings and the issue of rural depopulation:

- S1. Classroom presentation by the teachers of the important problem of rural depopulation, its possible causes, and its relevance for the sustainable development.
- S2. Sharing the main rural-development associations and identification of the most interesting areas for developing the actions with the students.
- S3. Classroom presentation of various proposals for the design of farms and agri-food buildings by the teachers.
- S4. Classroom debate involving students and teachers on the ideas collected during the previous stages, brainstorming, and exploring possible ways forward.
- S5. Development of agri-food building projects to address the social problem of rural depopulation (definition of the location, building type, and building design). Monitoring of the projects that the students developed by the teachers both in the classroom and in out-of-class tutorials.
- S6. Presentation, defense, and discussion of the proposals that were adopted and the designs that were developed.
- S7. Evaluation of the S-LP through a survey of open-ended questions whose questions and answers are presented in the following sections.

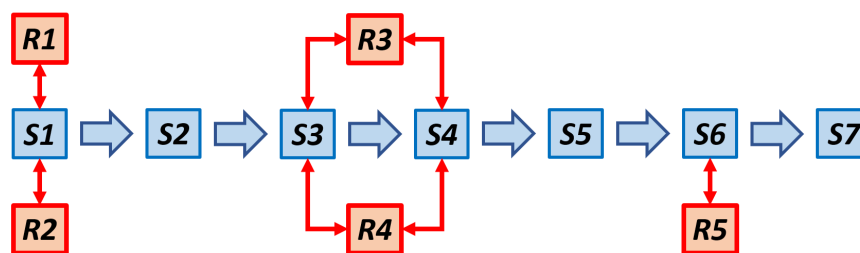
### 2.3.2. Reflection Activities

A series of activities for reflection, labelled *R*, were conducted during the S-LP. These activities consisted of a search for information followed by a debate in the classroom among the students themselves on the information found and the aspects related to the activity that the students were already familiar with. These debates, which were guided and moderated

by the teachers, aimed at getting the students to reflect together on the different aspects linked to the problem of rural depopulation, so that they would autonomously understand it as a whole in order to provide adequate solutions to it. These activities are detailed below:

- R1. Reflection on the rural areas with which the students were familiar (their village, or places they have visited for various reasons). Description of the existing population (number, age, professions, etc.). Identification of the main sources of income of the people living in these rural areas (agriculture, livestock, industry, tourism, etc.).
- R2. Definition of the type of environments (culture, art, nature, leisure, work, etc.) the general population is seeking and how to implement them in rural areas.
- R3. Identification of possible improvements to existing economic activities within rural areas.
- R4. List of potential businesses that could promote depopulated areas.
- R5. Discussion of possible sources of financing or fiscal measures, so as to implement the agri-food buildings that the students were designing.

The reflection activities were implemented at specific stages of the S-LP, as shown in Figure 2. The relationship between the stages of the S-LP and the reflection activities was bi-directional. Thus, the thematic of each stage was linked to the reflection activities that were conducted during it. In the same way, the reflection activities fostered learning and understanding of the social problem of rural depopulation in the students, which could be applied in the stage in which each reflection activity was performed and in subsequent ones.



**Figure 2.** Links between the stages and the reflective activities of the S-LP.

Apart from these activities, the students were encouraged to visit the areas they had selected to implement their projects and to contact the local authorities and any rural-development associations to learn about the state of the area, its depopulation level, its needs, and the actions related to the agri-food buildings that might potentially be most successful in addressing the depopulation problem.

The reduced number of students participating in the S-LP allowed all of them to participate in all the reflection activities actively and effectively. This could clearly lead to a better understanding of the problem of rural depopulation and to a greater awareness of it. This is an aspect that should be considered in the evaluation of the results obtained from this study and in their extrapolation to an S-LP performed with a larger number of students.

### 2.3.3. Service Outcomes

In the S-LP approach, the following aspects were defined as service outcomes, i.e., as targets to be achieved in relation to the problem of rural depopulation:

- Raising the visibility of depopulation within rural areas of the province of Burgos and the identification of areas for action.
- Awareness of the students with regard to the rural-depopulation problem, on which they can take an active position, as future agricultural engineers.
- Proposal of different measures for the creation and modernization of farms and agri-food industries in the identified areas of action that can improve the rural economy and thus the stability of the rural population.

#### 2.3.4. Student Competencies

It was finally established that the S-LP should provide student learning based on the development of the teaching competencies listed below. Learning was divided into three different dimensions: academic, personal, and social.

##### Academic competencies:

1. Learning the necessary procedures for the design and the dimensioning of the areas within an agri-food building.
2. Learning how to design the structural components of an agri-food building.
3. Understanding the applicability of the design concepts covered in the course in professional practice.
4. Design of a calculation report and plans for the design of an agri-food building.
5. Public presentation and defense of the need for an action or a design.

##### Personal competencies:

6. Knowledge and contact with social entities and public administrations related to the project to be undertaken, obtaining the necessary information from them.
7. Identification of the information sources that form the basis of the need or problem to be addressed.
8. Development of autonomy in the search for information and ways to engage with a specific problem.

##### Social competencies:

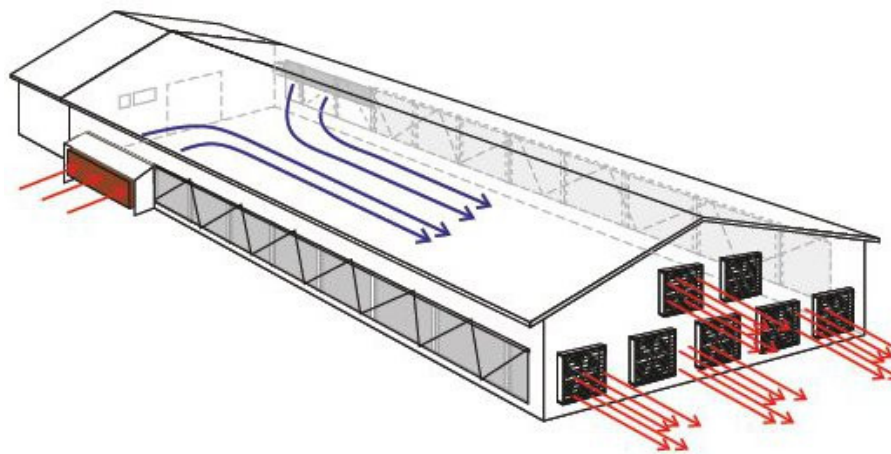
9. Internalization of the problem of rural depopulation and possible ways to address it, closely linked to the professional work of the agricultural engineer.
10. Understanding how the professional skills of an agricultural engineer can be applied to promote activities that can reduce depopulation based on their technical knowledge.
11. Learning how to identify social problems and to see the interface with their technical knowledge.

#### 2.4. Final Student Delivery

In this section, some of the projects of the students are briefly explained. The objective is to show how the students conceptualized the problem of rural depopulation and approached it through the development of agri-food buildings, based on all the information they were given during the stages and the activities of the S-LP. Since the projects were individually designed, only the most outstanding ones are presented below. Among the proposals were machinery storage buildings, grain storage facilities, feed storage facilities, poultry farms, swine farms, and composting plants. The students defined the location for their specific approach, after an independent search for information, and an analysis of the selected area and its features.

##### 2.4.1. Project 1

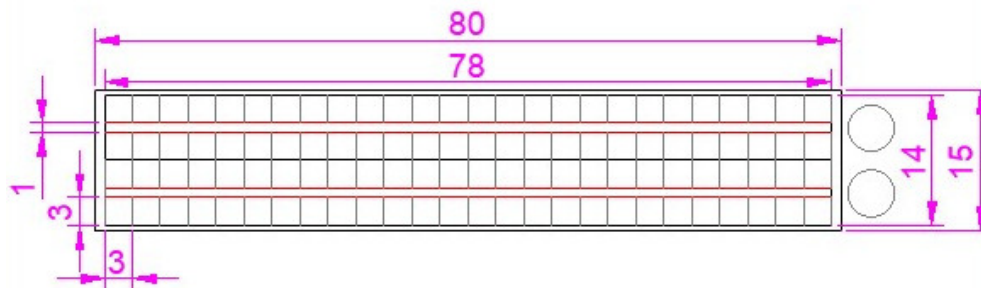
The first example of a project conducted by the students was a poultry farm located in the town of Monasterio de Rodilla, a municipality to the northeast of the city of Burgos, with a population of only 224 inhabitants. In view of the needs of the area, a building with a floor area of 2000 m<sup>2</sup>, a length of 100 m, and a width of 20 m was proposed. It would require an investment of EUR 330,000 with a 20-year investment payback period and could provide an estimated income per poultry fowl consignment of EUR 13,000. This building is illustrated in Figure 3 in which both the floor area and the ventilation are key aspects.



**Figure 3.** General view of the poultry farm [36].

#### 2.4.2. Project 2

The second example was a swine farm to be located in Castrillo Solarana, a municipality of approximately 178 inhabitants located to the south of the city of Burgos. A complex consisting of three annexed warehouses, each with a capacity for 1000 animals, was proposed. These buildings were designed with a length of 80 m, a width of 15 m, 104 pens of  $3 \times 3$  m, and two interior 1-m wide corridors, as detailed in Figure 4. The initial investment was estimated at EUR 300,000 with a 15-year payback period.



**Figure 4.** Swine housing dimensions.

### 3. Materials and Methods: Surveys to Assess the Service-Learning Project

#### 3.1. Surveys Conducted

After the completion of the S-LP, surveys were administered to both students and teachers to inquire into their opinions of the project. Open-ended questions were chosen so that both students and teachers could reflect on whatever they considered relevant. The questions were prepared on the basis of the research experience of the authors of the study [4,22] and on other similar studies [37,38].

The student survey consisted of two open-ended questions, which are shown below. The main objective of these questions was to ascertain the degree of understanding and awareness they had reached on the problem of rural depopulation, questioning them with regard to the utility of their designs and any other alternatives they might have proposed. Basically, the idea was to determine whether the service outcomes had been reached and whether the students had developed the social competencies set out in the S-LP.

1. Do you think that the agri-food buildings proposed by you and your classmates would really help to solve the problem of rural depopulation? What do you consider to be the main disadvantages for their success?
2. What other approaches from the agricultural-engineering approach can you think of to stop rural depopulation? Explain in detail what it would consist of and how it would address depopulation within the rural environment.

The teachers were given a survey consisting of six open-ended questions. The first four questions were formulated to discover their opinions of student learning, fundamentally determining whether they had acquired the academic and personal competencies established in the S-LP. The other two questions sought to ascertain the personal opinions of the teachers on the S-LP and their own learning during that time, with the aim of verifying the level of social awareness on rural depopulation that the S-LP generated, not only for the students, but also for the other actors, which is one of the central positive aspects of an S-LP teaching experience [23,24].

1. Were students involved with the S-LP, and what were their dynamics?
2. Were they more or less motivated than they were with other activities on the course?
3. Have the students learned the technical concepts of the course through the S-LP?
4. Have students developed the personal skills set as a goal throughout the S-LP?
5. What is your general assessment of the S-LP?
6. What personal lessons did you take home from the S-LP experience?

### 3.2. Analysis of the Results

Since all the survey questions were open-ended, the results were sentences. These texts were qualitatively analyzed, dividing them into independent units, and thereby obtaining text fragments; grouping the text fragments by the aspect they dealt with (utility of the project, relation to engineering, critical appraisal, etc.); and conducting a hierarchization in which the groups were ordered according to their importance and the number of text fragments they incorporated. In this way, a global vision was obtained from a series of individual elements [38]. In addition, there was continuous feedback among the authors of the study, so that the aforementioned process and the qualitative analysis previously carried out by the others was successively and progressively performed [6].

The large number of text fragments obtained in the answers to the first question of the student surveys and their complex grouping led to the qualitative results being complemented with a word-cloud mixed analysis to provide the results obtained with a more solid basis. This analysis simply consisted of counting the number of times a word was repeated in all texts and representing it in the form of a word cloud [39] where the frequency of repetition determined the size of the words, so the more frequently repeated words appeared in larger sizes [40].

## 4. Results and Discussion

### 4.1. Student Survey

#### 4.1.1. First Question: Utility of the Proposed Agri-Food Buildings

In their answers to the first question of the survey, the students showed a clear social awareness of the problem of rural depopulation. In addition, some of them also indicated the key role that they could play as agricultural engineers with regard to rural depopulation, as they recognized that they could place their technical knowledge at the service of society to try to solve this problem. It was therefore considered that the results had been achieved, and that the students had acquired the social competencies set out in the S-LP. As indicated in the bibliography, an S-LP is an educational learning experience that is useful to society, either because a problem is directly addressed or because awareness of a problem is raised among people who can engage with it in constructive ways [8,38]. These aspects were achieved in this case, as the future agricultural engineers claimed a role that they thought they could play in addressing the problem of rural depopulation.

*"[...] rural depopulation is a major problem facing all villages [...]"*

*"[...] people migrate to other places where the job offer is greater [...] employment must be generated in rural areas [...]"*

*"[...] implementing projects such as mine or those of my classmates which generate employment can help to ensure that depopulation is not so damaging [...]"*

*"The knowledge we acquire in this and other courses can be of help in the fight against depopulation [...]"*

In addition, a critical attitude surfaced among the students in relation to the different proposals. It was evident in the way that all the students critically valued the utility and effectiveness of the agri-food buildings developed both by themselves and by their classmates to counter the problem of depopulation. The development of critical thinking through S-LP projects, an aspect on which different authors agree, is a seed that can lead to proposals addressing deeply rooted social problems that, as is the case of rural depopulation [34], may not have a direct and immediate answer [10,11].

*"[...] I consider that building animal farms would be appropriate to generate settled populations, because they need personnel for the jobs that they involve [...] these jobs would be indefinite, since the animals need all-year-round care [...]"*

*"[...] the warehouses do not provide so many jobs directly, although having storage facilities available to farmers they may decide to plant in that area [...]"*

*"Both the composting plants and the feed storage facilities [...] are very attractive from the point of view of livestock farms [...]"*

*"[...] building warehouses in which to keep machinery generates no added value for the territory nor to keep a stable population."*

The development of critical thinking was also noted in the identification of problems to be solved in the proposed agri-food buildings and by listing complementary measures. The resolution of a deep-rooted social problem such as rural depopulation not only requires a good proposal, but that proposal also needs favorable conditions for it to be successfully developed [31,41]. It was therefore observed that all the activities developed within the framework of the S-LP led the students to acquire a global vision of the depopulation problem, and to address as many aspects as possible for a successful outcome. A well-developed S-LP with a social approach can raise awareness of social problems and their implications, so that projects can be proposed from a global perspective [17] that may in time be truly successful.

*"[...] poor planning and economic management of these projects can make them unsuccessful [...] therefore these two aspects must be borne in mind [...]"*

*"[...] the people involved in the starting agri-food industry need motivation and advice to start a successful project, which is always complicated [...]"*

*"[...] it must be noted that even if the proposed buildings are located in a rural municipality, it is necessary to encourage the people who work there to stay and live in that municipality, as there may be some who do not and live in other municipalities further away."*

*"[...] good management of the waste generated is necessary, fundamentally on farms [...] respect for the environment is fundamental in rural areas and without it no proposal will be valid [...]"*

Figure 5 shows the word cloud with the 10 words that the students repeated most when answering the first survey question and after removing the stop words (i.e., prepositions, determinants, etc.). As may be expected, words such as "depopulation", "rural", "farms", "storage", and "jobs" appeared in the word cloud, words that were directly linked to the problem of rural depopulation addressed in the S-LP. However, other words were also found that illustrated the aspects discussed above. First, the word "aware" showed student awareness of the social problem that was addressed. Second, the terms "technical", "role", and "engineer" revealed that the students could through the S-LP see the role they might play in solving this problem, based on their education as agricultural engineers. Finally, the term "overall" was indicative of the need to address this social problem bearing in mind all its facets, so that both effective and successful proposals might be implemented.



**Figure 5.** Word cloud for the first question of the student survey.

#### 4.1.2. Second Question: Other Possible Measures to Solve Rural Depopulation

The second question posed to the students was aimed at encouraging them to devise possible approaches to the problem of rural depopulation other than the construction of agri-food buildings. The purpose behind this question was to assess the degree of understanding and awareness of this problem that formed part of the S-LP, thus complementing the previous question, to evaluate the success of this teaching experience from the social viewpoint.

The first aspect to highlight is that many students continued to refer to the utility of designing agri-food buildings. It showed that the students considered it a useful approach to mitigate rural depopulation, even after the knowledge of this problem attained by the students during the S-LP. The social approach that can be adopted for some technical engineering courses is therefore clear, to awaken a sense of social service in future engineers [25,42].

*"[...] livestock farming is the sector with the most notable potential to fix rural population [...] livestock farmers are forced to live in the rural environment to run their businesses [...]"*

*"The best step forward would be to create farms or warehouses where there would be enough jobs [...]"*

*"[...] the option of building food processing/transformation factories that generate jobs in the villages can also be chosen, since no project related to this approach has been proposed [...]"*

However, the proposals of the students were not limited to agri-food buildings and addressed a wide range of other areas. Among them, ideas based on their future role as agricultural engineers could be found. This revealed an aspect already noted in the answers to the first question, which was the fact that the students established a clear link between their technical formation as agricultural engineers and the part they can play in solving social problems within their professional field. From a generic approach, the work of an engineer is to perform a social service [43], trying to respond to the needs of the population [44]. S-LP teaching experiences are a good way to awaken this vocation in engineers from the time of their training, so that it can be kept in mind throughout their whole professional life [27,30].

*"[...] there are fewer and fewer people who want to dedicate themselves to the agricultural sector, so promoting and developing social activities derived from or involving the agricultural sector by an agricultural engineer [...] I perceive it as a useful response."*

*“[...] the creation of industrial parks with companies within the agro-livestock sector where people can stay and work and so that rural workers do not have to go to the big cities to buy phytosanitary products and fertilizers [...]”*

*“[...] there are mountains that are full of weeds and extensive livestock farming is disappearing, which were responsible for clearing the mountains, so we could consider projects to clear up the mountains and improve rural roads, attract new population, generate jobs and improve the conditions of the rural environment [...]”*

Finally, projects related to financing and housing for people in rural areas were also proposed. As found in the answers to the first question, a global understanding of the problem of rural depopulation on the part of the students was noted. They were aware of the different aspects that needed to be considered, in order to address this problem; a fundamental aspect to be able to propose complete responses that cover all aspects and that can be really successful [23].

*“[...] the receipt of certain subsidies, such as those linked to the common agricultural policy, could be made conditional on living in the rural environment [...]”*

*“[...] to provide affordable housing for workers in the rural world [...] it would be beneficial for the municipality to have small pieces of land to plant or to raise vegetable gardens and animals, to encourage activity in the rural world [...]”*

*“[...] to implement new technologies, which many of the villages do not have such as Internet access, would be very helpful because farmers must present or share tables and reports with the amount of grain harvested for example.”*

*“Villages that are close to each other could coordinate the development of agricultural days, talks with experts in the field, increase the number of school trips to the countryside [...]”*

*“If there is a small or medium enterprise in a village, try to keep it in the village and hold sales days or market its products [...]”*

#### 4.2. Survey of Teachers

The survey administered to the teachers involved in the S-LP was intended to find out whether they thought the students had learned the concepts of the course, set as academic and personal competencies in the definition of the S-LP. In the end, the teachers were the ones who graded the projects and attended their presentations, so they had a clearer vision of this aspect [12]. In addition, their personal assessment of the S-LP was also requested and their own learning and implication, as an S-LP should ensure that all the actors become aware of the problem that is addressed [16,17].

##### 4.2.1. Evaluation of Students

The first question for the teachers was whether the students had been involved in the S-LP and whether they had shown interest and an active attitude towards it. The need to know these aspects was due to the fact that for a novel teaching experience to be successful, the first thing that must be awakened is the interest of the students. They are expected to learn not only from the aspects developed in class or the compulsory subjects forming part of the teaching experience [3], but also through self-learning by themselves [22]. The teachers' assessment of this aspect was positive, highlighting the independence and good communication of the students during the S-LP and their greater involvement as the S-LP progressed.

*“[...] the students have worked very well [...] also in the parts that required independence and collaboration with other classmates [...]”*

*“At all times there has been very good communication, both student-teacher and student-student [...]”*

*“From the very beginning, the students showed interest in the subject of S-LP, and they were more and more involved as they progressively explored the topic [...]”*

While the first question of the survey for the teachers sought to determine whether the students had been motivated, the second question asked about their degree of motivation. To that end, the teachers were asked to measure student motivation in comparison

with other activities performed on the course. A motivation level is a complex aspect to define [45,46], so it was thought that a good way of measuring it might be to take habitual practice on the course as a reference. Greater motivation is an indicator of a greater willingness and an active attitude towards learning the concepts of the course [47], possibly thanks to the greater interest aroused in the students [48]. In relation to this aspect, the teachers indicated that their perception of the motivation raised by the S-LP in the students could be equated to that of the workshop-practice part of the course, which was generally the part of the course in which the students showed the greatest interest. Thus, the teachers thought that the S-LP was a beneficial way for the students to approach the design aspects of agri-food buildings addressed in the course and considered it of clear utility.

*“The motivation for this activity has been high [...] it is an exercise that is very close to their professional activity in the near future and addresses a subject with an important social awareness [...].”*

*“[...] this course has workshop practices, which is the aspect in which the students are usually the most interested [...] the students showed a similar interest in the S-LP and in these practices [...] I think that both teachers are very satisfied with our involvement in the S-LP proposal [...].”*

The third and fourth questions asked the teachers whether the students had acquired the academic and personal competencies established in the S-LP. The acquisition of social competencies was assessed through the student survey. In the current teaching framework, student learning is based on the acquisition of competencies [49]. Their correct acquisition is an indication that the objectives of the course have been achieved [50]. It is therefore essential to assess the acquisition of the course competencies in a novel teaching experience, as the fundamental basis for this type of teaching activity must be that the students learn the necessary professional concepts [4]. The teachers gave positive responses to both types of competencies, indicating that each one had been properly acquired. The theoretical and practical concepts explained in class had been successfully applied during the projects, while in relation to personal competencies, the students had acquired the capacity for independent work and were able to search for and to digest the necessary information for successful development of the project. However, the teachers also indicated that some students showed weaknesses relating to that aspect, suggesting as a possible point of improvement for future S-LP experiences that teachers should guide students more closely in the first steps of an information search, instead of looking for highly independent work from the start.

*“The projects that were developed were technically sound [...] the design concepts explained in class were correctly applied [...].”*

*“[...] although there are small aspects that could be improved, as in any work done by students because in the end they are still learning, all the agri-food buildings that were developed could be implemented [...] they also had proper calculation reports and adequate plans [...].”*

*“[...] the students worked in many phases of the S-LP autonomously [...] possibly because they were addressing a problem close to them through the projects [...] on other occasions I detected that it was necessary to guide them more during the project [...].”*

*“In general, the students started out with adequate information that they themselves sought [...] however, more initial support in the search for information would have been beneficial in some cases [...] this would perhaps have helped to reduce the notable differences of level among the students between the geographical framing and the justification of the needs of the geographical area addressed in the project [...].”*

#### 4.2.2. Personal Opinion

In relation to the question referring to the overall assessment, the teachers stated that they were very satisfied. Their reflection focused on the idea that most engineers would play an active role in the improvement of their surrounding area, if they could, and agricultural engineers might therefore consider playing active roles to improve the rural

environment in which they work, an aspect that could be instilled in the students through S-LP experiences and which is the final objective of this type of teaching experience in engineering [24,29]. The teachers also highlighted the social awareness achieved through the S-LP.

*“[...] I think that in general we are very satisfied with the overall development of the experience [...]”*

*“We engineers are an active part of the process of improving the environment [...] and the needs of the rural environment must be addressed by agricultural engineers through economically and technically viable answers [...]”*

*“[...] this opportunity has brought the students closer to the reality of their professional field, raising their social awareness [...]”*

The last question that the teachers were asked addressed their own learning throughout the S-LP. The teachers recognized that they had learnt during the S-LP, as an S-LP experience generally raises awareness of a social problem that the participants have to address [14]. However, the teachers also emphasized that they had learnt three aspects through S-LP. First, it had helped them to consider new similar initiatives that they could apply to their courses, so as to encourage more active learning among the students [6]. Secondly, it had helped them to identify other social needs that an agricultural engineer can consider addressing and that addressing them in class can make the concepts explained more useful. Finally, it also enabled them to become aware of the role that the university can play in engaging with some societal problems. The university has professionals who are capable of solving these problems and has the necessary means to raise awareness of an issue and how to engage it [9,11].

*“[...] I think it is clear that not only the students, but we have also become aware of the problem of rural depopulation [...]”*

*“The reflective exercise that we have conducted [...] has helped us as teachers to consider new initiatives of this type [...] and we have also identified other social aspects in which we as technicians, both students and teachers, should become involved [...]”*

*“[...] the university is a very important entity to make known the great challenges of society [...] and that can be used to propose good approaches that could help to alleviate some current and future social needs”*

## 5. Conclusions

A Service-Learning Project (S-LP) was implemented on the Construction & Agroalimentary Building course of the third year of the Bachelor's Degree in Agroalimentary Engineering & the Rural Environment at the University of Burgos, Spain. The objective was to address the social problem of rural depopulation through the design of agri-food buildings for new industries and economic activities that could generate employment and workplaces and, thereby, a more stable population. This topic was chosen for the S-LP because it is a very pressing problem in the rural area of Spain, and for which agricultural engineers can play a key role in its solution, since it directly affects their field of action. After the completion of the S-LP, students were surveyed to elicit their opinions on this teaching experience in terms of the social-service approach, always bearing in mind that the S-LP had a hypothetical approach, without implementing and testing the effectiveness of the proposed agri-food buildings. The following conclusions can be drawn from the analysis of their responses:

- The S-LP raised awareness of the social problem of rural depopulation and the proposals to address it, not only among students but also among teachers. It has therefore been confirmed that an S-LP is a teaching experience that, if properly conducted, can awaken a social commitment in all those involved.
- Participation in the S-LP fostered a critical spirit among the students, so that they not only looked for answers to the problem, but also sought the best way to solve it. In addition, all the activities performed led the students to reach a global vision of the social need. It meant that when proposing ways to address the issue of rural

depopulation, they considered all its aspects and implications, so that the problem could be successfully addressed.

- Reflection on the social problem and the search for answers based on technical knowledge also helped the students to conceptualize a sense of social service as part of their profession as engineers. In this way, they realized that, as engineers, they could apply their technical knowledge to address existing social needs.

In addition to raising students' awareness and critical thinking about a social problem, an S-LP should also facilitate learning of the course content. Teachers were surveyed, to evaluate the level of learning of the students throughout the S-LP, and the following conclusions were drawn regarding this aspect:

- The S-LP aroused student interest and motivation to learn the concepts addressed during the course. Motivation levels were similar to those found in the workshop practices, the part of the course preferred by the students, perhaps because of the usefulness of the concepts that were directly applied to a social issue.
- The students acquired the academic and personal competencies proposed as the objective of the S-LP from the teachers' viewpoint. They therefore learned the technical concepts explained on the course and developed the capacity for autonomous work and searching for information, although in relation to this last aspect, it is important for the teacher to act as a guide in the first steps.
- Finally, the teachers themselves recognized that they had also learned throughout the S-LP, using this experience as a basis to propose new classroom dynamics and activities to favor active and socially committed learning. To that end, they recognized that it was necessary to rely on the university as a social entity that can make existing social problems visible and that can propose ways of engaging with these issues.

In this study, the advantages and the utility of conducting S-LP experiences, in this case in the field of agricultural engineering, have largely been demonstrated. However, it is also true that this is a teaching experience performed with only a few students on a particular course, which may have favored a greater awareness among them of the social problem of rural depopulation due to the ease with which all of them could actively participate in the S-LP activities. Thus, this limitation of the study could be addressed in the next steps of the research by considering S-LP experiences with larger numbers of students following other courses. In addition, S-LP experiences that simultaneously involve several courses could also be useful, thus overcoming the perception among students of the lack of a linkage between the concepts addressed on different courses.

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## Article

# Natural Disaster Prevention Literacy Education among Vietnamese High School Students

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**Abstract:** Research has shown that natural disasters can be prevented or mitigated effectively through education which provides knowledge and skills for the young generation to protect themselves and act to protect the community. The current study investigated the level of natural-disaster-prevention literacy and analyzed its predictors among high school students in Vietnam. This study adopted a cross-sectional school-based design, using an online survey. There were 807 students from seven public schools participating in this study. The results show that the natural-disaster-prevention knowledge, perception, skills, and overall literacy are above average, with knowledge having the highest score. Significant differences exist in natural-disaster-prevention literacy and its components by gender, grade, location, and residence. Age, location, residence, knowledge, and perception can predict participants' skills of natural-disaster prevention. This study highlights the necessity of teaching natural-disaster prevention in schools, across grades, and focusing on providing the students with the knowledge and perception needed to improve their natural-disaster-prevention skills. This will contribute to helping the country meet the goal of education for sustainable development.



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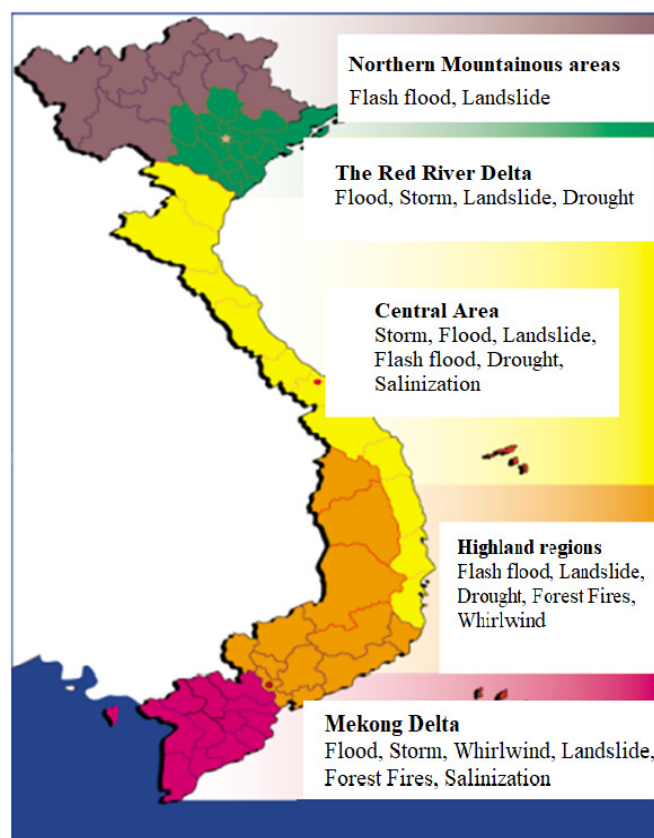
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**Keywords:** disaster-prevention literacy; education for sustainable development; geography education; high school; natural-disaster prevention; Vietnam

## 1. Introduction

Natural disasters are uncontrollable and can cause massive financial, social, economic, and environmental losses, such as deaths, severe injuries, food shortages, communicable diseases, and psychological impairment [1]. They occur due to the action of natural forces, including climate and geology. People consider natural disasters unfortunate but inevitable [1]. Some common sudden-onset disasters worldwide include earthquakes, floods, hurricanes, cyclones or typhoons, tornados, fires, tsunamis or storm surges, avalanches, volcanic eruptions, extreme cold or blizzards, and heat waves. In contrast, slow-onset ones include drought, famine, desertification, deforestation, and pest infestation [1]. According to the World Meteorological Organization (WMO) 2021 report “WMO Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2019)”, the world has witnessed more than 11,000 natural disasters from 1970 to 2019, causing more than 2 million human deaths and USD 3640 billion in damage. Over the past 50 years, there has been an average of one natural disaster related to weather, climate, flood, and drought each day, resulting in 115 deaths and USD 202 million in damage per day. More than 91% of deaths occur in developing countries. According to the report, natural disasters have increased fivefold during the above period, primarily due to the Earth’s warming. The report also emphasized the weather phenomena, extreme climate, and drought are becoming more frequent and severe in many parts of the world [2].

Vietnam is a Southeast Asian country along the Pacific Coast, with three sides bordering the sea. The territory has a narrow S shape. Hills and mountains occupy a quarter of the land area. Vietnam is located in the storm center of the South China Sea. In 2017, Vietnam ranked sixth globally on the list of countries most affected by natural disasters due to climate change [3]. According to the statistics of the Vietnam Central Steering Committee for Natural Disaster Prevention and Control, in the past 20 years alone in Vietnam, natural disasters such as storms, floods, and landslides have killed more than 13,000 people, with nearly 400 deaths or missing people each year, and destroyed over USD 6.4 billion of property, about 60% of the land area (Figure 1). Each year, the GDP is reduced by about 1–1.5% due to natural disasters, and this reduction has been increasing in recent years. More than 70% of the population was at risk of being affected by natural disasters [4]. Within the country, the Central and Central Highland regions, including 19 provinces and cities, are complex topographical areas. The Central Vietnam areas cover over 1900 km of coastline, while the Central Highlands include dense, short, and steep system of rivers and streams with over 740 rivers. This area suffers from the most types of natural disasters in Vietnam, with higher frequency and severity than other regions [5].



**Figure 1.** Map of major natural disasters in regions of Vietnam (Ministry of Education and Training, 2012).

Previous evidence has shown that injury and damage caused by natural disasters can be prevented or mitigated by various solutions, including education [6–8]. The role of education is highlighted as an essential strategy to achieve the four priorities outlined in the Sendai Framework for Disaster Risk Reduction 2015–2030 [9]. Disaster education's function, operational aspect, and cost-effective nature make it a valuable risk management tool [10]. The education of disaster-related information aims to improve disaster literacy. It is an individual's ability to read, use, and understand disaster information in disaster mitigation, preparedness, response, and recovery [11]. Without knowledge of natural disasters, students are vulnerable to unverified information circulating in cyberspace,

creating feelings of fear and intimidation [12]. The existence of disaster literacy can reduce or even eliminate the loss and injury caused by natural disasters. Disaster literacy can encourage students' efforts to understand what they have to do with disasters, forming students' responsibility and practice independence in the event of a disaster [11].

Besides having the knowledge of disaster (disaster literacy), it is also important to also have natural-disaster-prevention (NDP) literacy, which is defined as a person's personal knowledge, attitudes, and skills toward preventing disaster caused by the nature. It consists of three main components: disaster-prevention knowledge, disaster-prevention attitude, and disaster-prevention skills [13]. The NDP literacy is also understood as the development of proactive attitudes to apply disaster-prevention knowledge to respond to natural disasters and resilience and improve life after disasters [14]. NDP literacy is also defined as the sum total of abilities and skills, including perceptions, skills, and emotions, that enable an individual to respond, analyze, and reflect in the face of disaster for the sake of their lives. In general, NDP literacy involves having a correct understanding of life-threatening disasters, proactive attitude toward disaster information and disaster prevention, and adequate capabilities and skills for disaster prevention [14]. NDP literacy includes three indicators: disaster awareness, prevention knowledge, and response knowledge [15]. Attitudes toward NDP are assessed by indicators of sensitivity of disaster prevention, values related to NDP and responsibility for NDP, sensitivity of NDP, disaster-prevention-related value, and responsibility toward disaster prevention. NDP skills are a combination of preparedness and response activities [15]. Currently, different terms are used to refer to disaster education, such as "disaster education", "disaster-risk education", "disaster-reduction education", and "disaster-prevention education". Shaw et al. argue that all of the above terms are just different expressions of the same problem, and the basic meaning is natural-disaster-risk-reduction education [16]. As a country with many natural disasters, Vietnam quite commonly uses the above terms. In this study, we use the term "natural-disaster-prevention education" as a solution to provide knowledge and information about natural disasters for students and improve students' awareness and attitudes about natural disasters and response to natural disasters at the same time. This could help give students the skills to protect themselves, reduce damage, and overcome the consequences caused by natural disasters.

Some researchers confirmed that low perception and lack of understanding of risk negatively impact people's reactions to hazard warnings, personal protection measures, and recovery [17,18]. NDP literacy education aims to provide knowledge and skills for individuals and groups to take action to reduce their vulnerability before and during the disaster [19]. Children, in general, and school students are among the most vulnerable people in natural disasters. However, they can participate in disaster-response activities at home, at school, and in their community to manage the challenging situations they might counter before, during, and after natural disasters [20]. Disaster-prevention-literacy education in schools will be an excellent approach for children to equip them with knowledge and skills to protect themselves and help others. In addition, children can be a bridge to disseminate disaster-risk-reduction knowledge within their families and communities [20].

Nonetheless, education in natural-disaster-prevention (NDP) literacy in Vietnam has not shown the necessary effectiveness that requires scientists and educators to find out the reasons and the difficulties in this practice [21]. In recent years, the Vietnamese Government as well as the Ministry of Education and Training (MOET) of Vietnam have begun to focus on education on NDP and climate change in schools through circulars, decrees, policies, action plans, educational programs and projects, and projects in association with domestic and foreign organizations. Since the early 2010s, many educational projects have focused on climate-change response and risk reduction. Natural disasters have occurred in many provinces throughout Vietnam. Most of these projects promote two main initiatives: making schools safer and integrating climate-change and disaster-risk reduction into school curricula. Most notably, 14 major programs and projects are implemented by the MOET of Vietnam and other organizations, piloted in some schools, and implemented in a number

of at-risk areas on natural disasters in order to develop educational manuals on disaster prevention for some localities in Vietnam. More than 50% of these programs and projects are implemented by International Non-Governmental Organizations (INGOs) and NGOs in Vietnam.

Disaster-prevention education in Vietnamese schools is mainly carried out through extracurricular lessons, experiences, organized drills, injury-prevention practice, swimming lessons, and events; a natural-disaster-prevention exam; integration into the curriculum of subjects with relevant knowledge in high schools; and the development manuals for students, teaching materials for teachers, and training for teachers and students. With the positive results, many schools and high school students in the country have had positive changes in their awareness, knowledge, and skills of disaster prevention. However, due to limitations in funding, time, location, materials, and difficulties in integrating them into the curricula in high schools, the effect has not been widespread. The locality has not yet had access to disaster-prevention education. Natural disasters continue to happen and are becoming more and more anomalous and unpredictable, causing considerable consequences for the country and the people of Vietnam. Therefore, disaster-prevention education needs to be carried out regularly and continuously in many respects [22,23]. This study investigated the level of NDP literacy and analyzed the predictors of NDP literacy and its components among high school students in Vietnam.

## 2. Materials and Methods

### 2.1. Participants

This study used a cross-sectional design to collect data from students at high schools in Vietnam's Central and Central Highland areas. The study employed a purposive sampling method. The two selected study settings suffer from the most frequent and severe natural disasters each year in this country, in the form of storms, floods, landslides, flash floods, droughts, salinization, forest fires, and tornados [24]. There were 807 completed questionnaires (response rate 93.3%), of which 62.7% were completed by female students. The mean age was 17.06 (SD = 0.82). A brief summary of the participants' demographic information is presented in Table 1.

**Table 1.** Demographic information regarding participants.

|           |                | No. | %     | Mean (SD)    |
|-----------|----------------|-----|-------|--------------|
| Sex       | Male           | 301 | 37.3  | -            |
|           | Female         | 506 | 62.7  | -            |
| Age       | 18             | 297 | 36.8  | 17.06 (0.82) |
|           | 17             | 265 | 32.8  |              |
|           | 16             | 245 | 30.4  |              |
| Province  | Gia Lai        | 460 | 57.0  | -            |
|           | Thua Thien Hue | 347 | 43.0  | -            |
| Residence | Rural          | 637 | 78.9  | -            |
|           | Urban          | 170 | 21.1  | -            |
| Total     |                | 807 | 100.0 |              |

### 2.2. Procedure

The data collection was conducted from September 2021 to December 2021. Due to the complicated situation of COVID-19, the survey was conducted online via Google Forms. The public schools that are in the area with a high risk of natural disasters were introduced by the Provincial Department of Education and Training. Principals of potential randomly selected schools were contacted with a clear explanation of aims, processes, and participants' tasks. Schools that agreed to participate would be contacted for the next step. Three high

schools in Thua Thien Hue Province (Cao Thang, Nguyen Truong To, and Tam Giang) and four in Ayun pa, Gia Lai Province (Phan Chu Trinh, Nguyen Tat Thanh, Le Thanh Tong, and Ly Thuong Kiet) agreed to participate the study. Classes within these schools were randomly selected. The principals then informed classroom teachers. The research team then contacted them and scheduled times to visit the online class to work with potential participants. All information related to the study, including participants' tasks, benefits, and risks, as well as the voluntary nature of the participation and withdrawal, was clearly explained to students. Participants understood that they needed to get permission from parents before completing the questionnaire. A study information sheet and consent form were delivered via email to each student to bring home and seek permission from parents by having them sign the consent form. All students in selected classes were invited to participate in the study. The research team joined the online class one week later to collect the consent forms and start the data collection. The online Google Form questionnaire (in Vietnamese language) was delivered to students by classroom teachers during one online class. Students completed the online questionnaire on their own time. If the students completed and submitted the questionnaire, this meant that they and their parent(s) agreed to participate in the study. The email address and contact number of the researcher team was available in the online form for students and parents to contact for further information. The questionnaire took the students around 20 min to complete.

### 2.3. Materials

This study investigated the status of NDP capacity among high school students, including knowledge, perception, skills, and access level. A self-reported questionnaire was developed specifically for this study based on numerous reliable references (Table 2). The questionnaire includes 44 items in a five-option Likert scale design (see Appendix A). The knowledge component, which is the fact or condition of knowing something with a considerable degree of familiarity through experience, association, or contact, consists of nine items. The perception component, which is the awareness of the importance and necessity for preparing for natural disasters, includes eighteen items. Skill, which refers to the ability to act for natural disaster prevention, contains ten items, and access level to NDP education consists of seven items. The score for each subscale was calculated by determining the average of all relevant items.

**Table 2.** Questionnaire's components and reference sources.

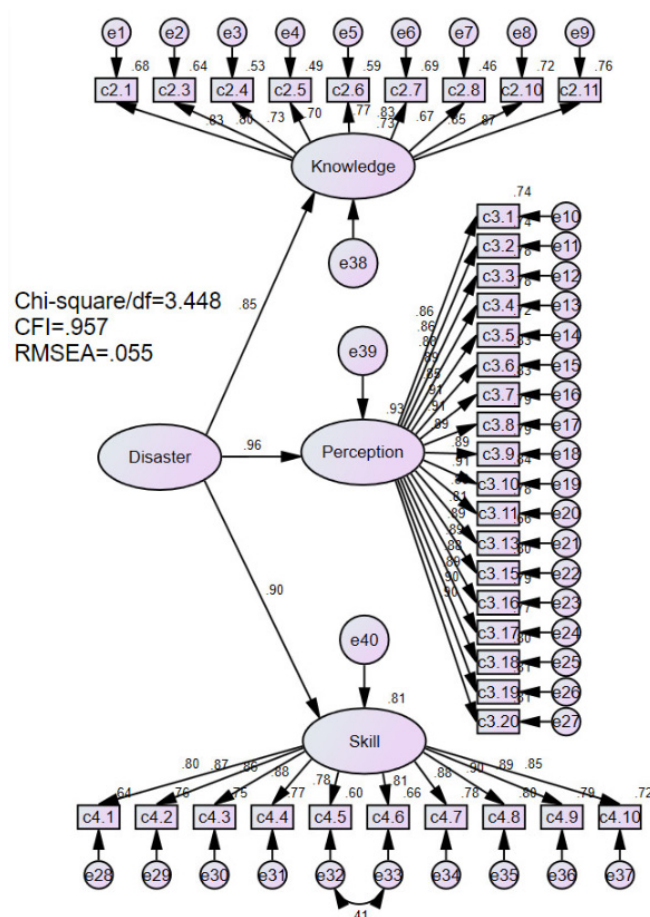
| Component                                     | Items | Reference Sources |
|-----------------------------------------------|-------|-------------------|
| Knowledge                                     | 09    | [8,25–27]         |
| Perception                                    | 18    | [8,25,27–29]      |
| Skills                                        | 10    | [1,8,27,30]       |
| Access level to disaster-prevention education | 07    | [23]              |

Two experts in education and geography evaluated the questionnaire. The questionnaire's first version was pilot tested on 27 high school students in Hue City. Students in the pilot study were excluded from the main survey. Comments from students were collected. The experts re-evaluated the questionnaire to finalize the last version used for the main analysis. This study used internal reliability with Cronbach's Alpha index. According to Lance and his colleagues, a Cronbach's Alpha above 0.70 is acceptable [31]. The Cronbach's Alpha for NDP knowledge, perception, and skills and overall NDP in this study were 0.94, 0.98, 0.96, and 0.98, respectively.

### 2.4. Data Analysis

In order to test the construct validity of the questionnaire, we submitted the data to a confirmation factor analysis (CFA), using Amos version 20.0 software, to evaluate

the model's fit. We used the maximum likelihood and covariance matrices. According to Hu and Bentler [32] and Kline [33], the index for a fit model includes Normed  $\chi^2$  ( $\chi^2/\text{df}$ )  $\leq 5$ ; CFI  $> 0.90$ ; RMSEA  $\leq 0.08$ ; SRMR  $\leq 0.08$ . We conducted the three-factor model (knowledge, perception, and skill) based on the NDP framework, conceptualizing NDP as an umbrella term for a variety of interdependent and integrated factors. The indexes for the three-factor model are Normed  $\chi^2$  ( $\chi^2/\text{df}$ ) = 3.448; CFI = 0.957; RMSEA = 0.055; SRMR = 0.0233 (Figure 1). The model fits these data (Figure 2).



**Figure 2.** Three-factor model of the NDP questionnaire.

Descriptive statistics were run to identify the mean and standard deviation of natural disaster knowledge, perception, and skills. Demographic variables (sex, grade, urban/rural, and residence location) were collected. An independent *t*-test was used to examine the differences between groups in natural-disaster knowledge, perception, and skills. The correlation between knowledge, perception, and skills related to natural disasters among students was identified by Pearson value *r*, in which the correlation was counted with a significant *p*-value under 0.05 [34]. Several stepwise linear regressions were conducted to investigate the predictive roles of different factors in natural-disaster-prevention literacy. The first stepwise linear regression included knowledge of natural-disaster prevention as an outcome variable, and demographic information and level of access to NDP education as independent variables. Perception about NDP was an outcome variable in the second linear regression, with the independent variables being demographic characteristics, level of access to NDP, and NDP knowledge. Potential predictive factors of NDP skills were examined in the third stepwise linear regression, in which demographic characteristics, level of access to NDP, NDP knowledge, and perception were independent variables.

### 3. Results

#### 3.1. Preliminary Analyses of Natural-Disaster-Prevention Literacy among Vietnamese Students

The data in Table 3 show that students' knowledge, perception, and skills are above average (mean ranges from 3.22 to 3.73). The total NDP score is 10.75, which is above average. There are significant positive correlations between knowledge, perception, and skills of NDP ( $p < 0.05$ ). All of the three components are well correlated with the total score of NDP ( $p < 0.01$ ). Moreover, positive correlations are found significantly among knowledge, perception, skills ( $p < 0.05$ ), NDP literacy ( $p < 0.01$ ), and the level of access to NDP education.

**Table 3.** Preliminary analyses of NDP literacy among Vietnamese students.

|                      | Min–Max | $\bar{X}$ | SD   | 2      | 3      | 4       | 5       |
|----------------------|---------|-----------|------|--------|--------|---------|---------|
| NDP knowledge        | 1–5     | 3.46      | 0.83 | 0.78 * | 0.77 * | 0.90 ** | 0.50 *  |
| NDP Perception       | 1–5     | 3.73      | 0.92 | 1      | 0.84 * | 0.95 ** | 0.54 *  |
| NDP skills           | 1–5     | 3.57      | 0.86 |        | 1      | 0.92 ** | 0.61 *  |
| Total NDP score      | 3–15    | 10.75     | 2.42 |        |        | 1       | 0.59 ** |
| NDP education access | 1–5     | 3.22      | 0.85 |        |        |         | 1       |

\* Correlation is significant at the 0.05 level (2-tailed). \*\* Correlation is significant at the 0.01 level (2-tailed).  $\bar{X}$ , mean; SD, standard deviation; NDP, natural-disaster prevention.

#### 3.2. Sex as an Independent Level

The results from the *t*-test analysis show that female students are significantly higher than male students in all components of natural disaster literacy, including knowledge, perception, and skills ( $p < 0.05$ ). Overall, females show significantly higher scores in NDP literacy than their male counterparts ( $p < 0.01$ ). They also show a higher level of access to natural-disaster-prevention education ( $p < 0.05$ ) (Table 4).

**Table 4.** Differences in natural-disaster-prevention literacy by sex among Vietnamese students.

|                      | Male      |      | Female    |      | <i>t</i> (807) | <i>p</i> |
|----------------------|-----------|------|-----------|------|----------------|----------|
|                      | $\bar{X}$ | SD   | $\bar{X}$ | SD   |                |          |
| NDP knowledge        | 3.39      | 0.90 | 3.51      | 0.79 | −1.96 *        | 0.05     |
| NDP Perception       | 3.61      | 0.99 | 3.80      | 0.88 | −2.64 *        | 0.01     |
| NDP skills           | 3.44      | 0.97 | 3.63      | 0.78 | −2.92 **       | 0.004    |
| Total NDP score      | 10.44     | 2.72 | 10.93     | 2.21 | −2.79 **       | 0.005    |
| NDP education access | 3.18      | 0.90 | 3.25      | 0.81 | 1.50           | 0.30     |

\* Correlation is significant at the 0.05 level (2-tailed). \*\* Correlation is significant at the 0.01 level (2-tailed).  $\bar{X}$ , mean; SD, standard deviation; NDP, natural-disaster prevention.

#### 3.3. Grade as Independent Level

Regarding the total NDP score, three grade groups of 10, 11, and 12 were considered. Overall, there are significant differences across groups in NDP knowledge, perception, skills, and overall literacy. Specifically, students in grade 10 have higher scores in knowledge ( $p < 0.001$ ), perception ( $p < 0.001$ ), skills ( $p < 0.01$ ) and overall literacy ( $p < 0.001$ ) than those in grade 11. Grade 10 students are higher than their grade 12 schoolmates in the score of knowledge ( $p < 0.05$ ), perception ( $p < 0.05$ ), and overall literacy ( $p < 0.05$ ). When comparing between grades 11 and 12, grade-12 students seem to have higher scores in skills and overall NDP score. There are no differences in knowledge and skills between grades 11 and 12. Moreover, all three grades show no disparities in accessing NDP education ( $p > 0.05$ ) (Table 5).

**Table 5.** Differences in natural-disaster-prevention literacy by grade among Vietnamese students.

|    |    | NDP Knowledge  |          | NDP Perception |          | NDP Skills     |          | Overall NDP Score |          | NDP Education Access |          |
|----|----|----------------|----------|----------------|----------|----------------|----------|-------------------|----------|----------------------|----------|
|    |    | $\bar{X}$      | SD       | $\bar{X}$      | SD       | $\bar{X}$      | SD       | $\bar{X}$         | SD       | $\bar{X}$            | SD       |
|    | 10 | 3.64           | 0.67     | 3.92           | 0.76     | 3.69           | 0.77     | 11.25             | 1.96     | 3.26                 | 0.80     |
|    | 11 | 3.31           | 0.81     | 3.56           | 0.93     | 3.40           | 0.86     | 10.28             | 2.40     | 3.15                 | 0.84     |
|    | 12 | 3.46           | 0.94     | 3.71           | 1.01     | 3.61           | 0.91     | 10.76             | 2.70     | 3.26                 | 0.89     |
|    |    | <i>F</i> (804) | <i>p</i> | <i>F</i> (804) | <i>p</i> | <i>F</i> (804) | <i>p</i> | <i>F</i> (804)    | <i>p</i> | <i>F</i> (804)       | <i>p</i> |
| 10 | 11 | 0.33 ***       | 0.000    | 0.37 ***       | 0.000    | 0.28 **        | 0.001    | 0.97 ***          | 0.000    | 0.12                 | 0.269    |
|    | 12 | 0.18 *         | 0.028    | 0.21 *         | 0.023    | 0.08           | 0.507    | 0.49 *            | 0.048    | 0.01                 | 0.999    |
| 11 | 12 | −0.15          | 0.083    | −0.15          | 0.125    | −0.20 *        | 0.015    | −0.49 *           | 0.043    | −0.11                | 0.251    |

\* Correlation is significant at the 0.05 level (2-tailed). \*\* Correlation is significant at the 0.01 level (2-tailed).

\*\*\* Correlation is significant at the 0.001 level (2-tailed).  $\bar{X}$ , mean; SD, standard deviation; NDP, natural-disaster prevention.

### 3.4. Location as Independent Level

Observing the result from the *t*-test analysis, we see that students in Thua Thien Hue are significantly higher than students in Gia Lai in NDP literacy and all its components, including knowledge, perception, and skills ( $p < 0.001$ ). However, there is no difference in the level of access to natural-disaster-prevention education ( $p > 0.05$ ) (Table 6).

**Table 6.** Differences in natural-disaster-prevention literacy by location among Vietnamese students.

|                      | Thua Thien Hue |      | Gia Lai   |      | <i>t</i> (807) | <i>p</i> |
|----------------------|----------------|------|-----------|------|----------------|----------|
|                      | $\bar{X}$      | SD   | $\bar{X}$ | SD   |                |          |
| NDP knowledge        | 3.60           | 0.82 | 3.36      | 0.83 | 4.21 ***       | 0.000    |
| NDP Perception       | 3.90           | 0.96 | 3.60      | 0.87 | 4.58 ***       | 0.000    |
| NDP skills           | 3.73           | 0.86 | 3.44      | 0.85 | 4.61 ***       | 0.000    |
| Overall NDP score    | 11.23          | 2.45 | 10.39     | 2.34 | 4.93 ***       | 0.000    |
| NDP education access | 3.26           | 0.77 | 3.19      | 0.90 | 1.11           | 0.269    |

\*\*\* Correlation is significant at the 0.001 level (2-tailed).  $\bar{X}$ , mean; SD, standard deviation; NDP, natural-disaster prevention.

### 3.5. Residence as Independent Level

An independent samples *t*-test was used to examine whether there is any difference in NDP overall score among students living in rural and urban areas. There are statistically significant differences in students' NDP overall score in urban and rural areas of Vietnam. The analysis revealed that urban students are better in regard to knowledge, perception, skills, and overall score in NDP ( $p < 0.001$ ) (Table 7). They are also the group with higher access to NDP education than those growing up in rural areas.

### 3.6. The Potential Predictive Factors of Natural-Disaster-Prevention Literacy among Vietnamese Students

Three stepwise linear regressions were conducted with the outcome variables NDP knowledge, perception, and skills, respectively. The final stepwise results are illustrated in Table 8.

Our study shows that demographic information, including age, location, and residence, can predict and explain 3.9% variance of the students' knowledge of NDP ( $p < 0.05$ ). It can explain 4.7% variance of the NDP perception ( $p < 0.05$ ), but it is unable to predict NDP skills ( $p > 0.05$ ). The education-access level significantly predicts NDP knowledge, perception,

and skills ( $p < 0.001$ ), and it contributes to 23.7%, 31.5%, and 35.4% the variance of the NDP knowledge, perception, and skills, respectively.

**Table 7.** Differences in NDP literacy by residence among Vietnamese students.

|                      | Urban     |      | Rural     |      | <i>t</i> (807) | <i>p</i> |
|----------------------|-----------|------|-----------|------|----------------|----------|
|                      | $\bar{X}$ | SD   | $\bar{X}$ | SD   |                |          |
| NDP knowledge        | 3.70      | 0.80 | 3.40      | 0.83 | 4.18 ***       | 0.000    |
| NDP Perception       | 3.99      | 0.96 | 3.66      | 0.90 | 4.18 ***       | 0.000    |
| NDP skills           | 3.80      | 0.84 | 3.50      | 0.86 | 3.96 ***       | 0.000    |
| Overall NDP score    | 11.48     | 2.41 | 10.56     | 2.39 | 4.49 ***       | 0.000    |
| NDP education access | 3.30      | 0.75 | 3.20      | 0.87 | 1.37           | 0.169    |

\*\*\* Correlation is significant at the 0.001 level (2-tailed).  $\bar{X}$ , mean; SD, standard deviation; NDP, natural-disaster prevention.

**Table 8.** Predictive factors to natural-disaster-prevention literacy among Vietnamese students.

|                |                        | <i>B</i> | <i>t</i>  | <i>R</i> <sup>2</sup> Change |
|----------------|------------------------|----------|-----------|------------------------------|
| NDP Knowledge  | Sex                    | 0.05     | 1.69      | 0.039                        |
|                | Age                    | −0.08    | −2.64 **  |                              |
|                | Location               | −0.09    | −2.55 *   |                              |
|                | Residence              | −0.08    | −2.14*    |                              |
|                | Education-access level | 0.49     | 16.19 *** | 0.237                        |
| NDP Perception | Sex                    | 0.04     | 1.89      | 0.047                        |
|                | Age                    | −0.03    | −1.37     |                              |
|                | Location               | −0.05    | −2.05 *   |                              |
|                | Residence              | −0.01    | −0.52     |                              |
|                | Education-access level | 0.21     | 8.57 ***  | 0.281                        |
| NDP Skills     | NDP Knowledge          | 0.66     | 26.59 *** | 0.315                        |
|                | Sex                    | 0.04     | 1.94      | 0.043                        |
|                | Age                    | 0.03     | 1.88      |                              |
|                | Location               | −0.03    | −1.58     |                              |
|                | Residence              | −0.01    | −0.11     |                              |
|                | Education-access level | 0.20     | 9.46 ***  | 0.354                        |
|                | NDP Knowledge          | 0.14     | 4.90 ***  | 0.214                        |
|                | NDP Perception         | 0.61     | 20.30 *** | 0.132                        |

\* Correlation is significant at the 0.05 level (2-tailed). \*\* Correlation is significant at the 0.01 level (2-tailed). \*\*\* Correlation is significant at the 0.001 level (2-tailed).  $\beta$ , Standardized Coefficients Beta; NDP, natural-disaster prevention.

Among various components of NDP literacy, knowledge plays a role in predicting perception and contributing to 31.5% variance of this variable. Both knowledge and perception positively predict skills with the contribution of 21.4% and 13.2% variance of the skill variable.

#### 4. Discussion

This study is the first of its kind in Vietnam investigating the predictors of NDP. A rational statistical analysis was used to reach the study's aims. Data from this study were obtained by school-based surveys in Central and Central Highland public schools of Vietnam with an acceptable sample size and high response rate.

To ensure objective research results, scales were built and evaluated for reliability and validity. The research results show that the scales have satisfactory reliability based on Cronbach's Alpha values [31]. The structural brute force is in agreement with the data of this study [32,33].

#### 4.1. Overall Natural-Disaster Prevention

Overall, NDP knowledge, skills, and perception among high school students in this sample is relatively high. Recently, the Government and the Ministry of Education and Training of Vietnam have begun to focus on disaster-prevention and climate-change education in schools through circulars, decrees, policies, action plans, and educational programs and projects associated with domestic and foreign organizations. Since the early 2010s, many educational projects on climate-change response and risk reduction of natural disasters have been carried out in many provinces throughout Vietnam. The most significant are 14 major programs and projects implemented by the Ministry of Education and Training of Vietnam and other organizations. More than 50% of programs and projects are implemented by International Non-Governmental Organizations (INGOs) and NGOs in Vietnam. Disaster-prevention education in Vietnamese schools is carried out mainly through extracurricular lessons, integration into the curriculum of subjects with relevant knowledge in high schools, development of references for students, teaching materials for teachers, and training for teachers and students. Many schools and high school students across the country have benefited from these projects and positively changed NDP's perception, knowledge, and skills. However, looking closer at this study's result, we see that the level of NDP overall score is not as high as expected. This might be due to limitations regarding time and materials, difficulties in integrating them into the curricula in high schools, and the fact that the effect has not yet been scaled up properly. Natural disasters continue to happen and are becoming increasingly unconventional and unpredictable, causing significant consequences for the country and the people of Vietnam. Therefore, in many aspects, NDP overall score education must be carried out regularly and continuously [35].

It seems that knowledge is the component that the school and teachers need to focus on improving for students. Although perception is the strength of students, it appears to be lower than expected, as perception plays a crucial role in students' decision to improve knowledge and skills. A study by Wei et al. [36] found that participants with lower knowledge of NDP are more likely to have lower coping skills and are more vulnerable to disasters. Previous studies shared similar findings among schoolteachers and administrators [14,37], in which participants' knowledge and perception of disaster prevention were high.

Our findings confirmed a significant correlation between different components of the NDP overall score. In other words, NDP knowledge, perception, and skills are highly associated. The conclusion is supported by the model of disaster-prevention literacy recommended by Yeh [13].

#### 4.2. Natural-Disaster Prevention by Demographic Information

It is found that female students have better performances of NDP in knowledge, perception, and skills. Similarly, Ku and Li [38] found that females had better average scores than males in terms of perception. This is also consistent with some previous studies that suggest that women's awareness, knowledge, and attitudes toward natural disasters are higher than men's because women are among the vulnerable groups when natural disasters occur, so they are more at risk than men [28,39,40]. Differences in knowledge and vulnerability make women more prone to anxiety and appreciate the importance of disaster preparedness than men [41]. Therefore, women will pay more attention to raising awareness, equipping them with knowledge and skills for disaster prevention to feel secure and ensure their own safety. Thus, in disaster-prevention education, gender should also be paid attention to in order to have appropriate educational activities. Female students should be more involved in education and disaster-prevention practices to improve their ability to cope with disasters and reduce stress and anxiety.

However, this finding is also different from results among schoolteachers and administrators in Taiwan [36] and Turkey [42], in which there was no disparity between males and females across three components of NDP. A study by [43] among teachers and students in Indonesia found that males had higher levels of disaster literacy than females. One

possible explanation for this disparity is the difference in the samples' age. The participants engaging in these studies included adults and elementary students. Furthermore, females are taught in school that they are at higher risk of being vulnerable to natural disasters than males due to their limited physical health because of biological differences and nutrition deficits, as well as the lack of survival skills such as swimming and tree climbing, which are traditionally taught to males [44]. Hence, females are more likely to pay more attention to improving their NDP literacy than their male counterparts.

Among grades 10, 11, and 12, it seems that grade 10 students were better than their elder peers. Specifically, grade 10 students had the highest knowledge, perception, and literacy scores. Grade 10 students also had a higher score in perception than grade 11 but not significantly higher than grade 12 students. Grade 12 students were better in skills than their grade 11 counterparts but still lower than those in grade 10. Grade 11 students seemed to have the lowest scores across components and overall score. It can be explained that NDP had been included in the national curriculum in Vietnam, especially in geography. The background knowledge of NDP had been included in grade 10's curriculum, and the NDP skills had been included in grade 12's curriculum, while grade 11's curriculum included little NDP overall score. One suggestion might be that the NDP content should be carried out continuously across three grades in high schools to consolidate knowledge and serve as a background for the transition from knowledge and perceptions to skills. Thus, the ability to put it into practice when a natural disaster occurs can bring greater efficiency.

Our study reveals that the NDP overall score differs by province and residence. It is more likely that students in Thua Thien Hue province and urban areas had higher scores in all aspects of NDP than those from Gia Lai province and those living in rural areas. Gia Lai Province is a mountainous area with many minor ethnic communities. This area's local economy and quality of life are low compared to other sites. The lack of materials and facilities is one of the most widespread problems in this area. Some students over 14 tend to be absent from school to take care of housework or farm work. Therefore, the capacity to approach NDP education and absorb knowledge is under-expected. On the other hand, Thua Thien Hue Province includes a big city with services as the main background of the local economy. Thua Thien Hue is considered the oldest educational and cultural center in Vietnam. Hence, the accessibility of students to education and NDP education is better. Our finding is in line with the study by [45], which concluded that students living in the city were more confident and had higher coping skills toward natural disasters.

Another noticeable finding in this study is that the level of access to NDP education remains similar across the high school students of different sex, grade, location, and residence. This may indicate that the access to NDP education of high school students is mainly through the national education program and projects, which is compulsory programs at schools in Vietnam; therefore, the level of access to NDP seems to be the same across groups.

#### *4.3. Natural-Disaster Prevention and Predictive Factors*

Educational access level seems essential in predicting high school students' knowledge, perception, and skills. The opportunities for students to expose themselves to NDP education, such as workshops, short training courses, literacy competitions, and campaign involvements, can improve students' perception, understanding, and skills in countering and coping with natural disasters. Besides the national curriculum, schools should provide students with more NDP-related activities.

There are some relationships between knowledge, perception, and skills. Knowledge can strongly predict perception. Knowledge and perception can strongly predict skills. The appropriate perception is the guideline leading to the appropriate actions. To be well aware of NDP, students first need to have a clear understanding of natural disasters and prevention measures. Therefore, it is necessary to teach students about this issue through different informative channels. However, the proper knowledge and perceptions themselves are not enough for high school students to have the ability to respond to

natural disasters. It is necessary to train students to have related skills. Disaster-prevention skills are built on the knowledge base and practical activities and experiences to help students effectively perform an action when a disaster occurs. For example, swimming skills are helpful in floods, and first-aid skills and escape skills are needed in urgent cases, as well as protecting-the-house skills, preparing emergency bags and search and rescue, and propaganda skills.

#### 4.4. Limitations and Direction for Future Research

There are several limitations that the readers should be aware of while interpreting this study's findings. First, this is a cross-sectional study; hence, any found correlations and predictions are well applied to the point of conducting the study only. Future studies should employ a longitudinal design to enhance the reliability of the study. Second, the current study focuses only on some factors, such as age, location, and residence. The findings from current study call for further exploration into the impact of other factors on knowledge, awareness, and skills of disaster prevention of Vietnamese high school students, such as experience of natural disasters, home education, and parents' education level, in future research. Third, the study focused on two regions in the Vietnam's Central and Central Highland areas, including seven schools. This limitation may influence the generalizability of the findings. It puts forward the importance to replicate the study by expanding the research scale and research area in order to attract a large number of high school students from many provinces in Vietnam to participate. Fourth, the exclusion of out-of-school students is another limitation of this study. This suggests that the conclusion of this study should be interpreted with caution when applying in other populations.

### 5. Conclusions

This study investigated the NDP overall score and identified related factors among high school students in the Central Highland and Central areas of Vietnam. The study's findings revealed that the NDP overall score among students was above average but under the expected level. There are many factors related to the NDP overall score, such as education-access level, age, location, and residence.

Considering the unexpected and increased frequency of natural disasters in Vietnam, especially in Central Highland and Central areas, the local government should develop a program of NDP throughout each high school grade, with numerous forms of teaching and learning activities. Extracurricular programs should include NDP content in their regular activities. Furthermore, improving skills should go together with enhancing the knowledge and perception of NDP. This will help the national education curriculum to meet the goal of education for sustainable development.

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## Appendix A. Questionnaire (English Version)

**Table A1.** Below is a list of statements on Natural Disaster Prevention Literacy Education. Please indicate how strongly you agree or disagree with each statement.

| No.       | Statement                                                                                                                                                                            | Level of Agreement    |              |                |                 |                          |
|-----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|--------------|----------------|-----------------|--------------------------|
|           |                                                                                                                                                                                      | Strongly Agree        | Agree        | Neutral        | Disagree        | Strongly Disagree        |
| <b>I</b>  | <b>Knowledge</b>                                                                                                                                                                     |                       |              |                |                 |                          |
| 1         | A natural disaster is an abnormal natural phenomenon that can cause damage to people, property, the environment, living conditions, and socioeconomic activities.                    | 1                     | 2            | 3              | 4               | 5                        |
| 2         | The increase in intensity, frequency, and anomalous degree of natural disasters in the current period is due to a combination of nature and human activities causing climate change. | 1                     | 2            | 3              | 4               | 5                        |
| 3         | Some natural disasters are predictable in terms of duration, intensity, and frequency.                                                                                               | 1                     | 2            | 3              | 4               | 5                        |
| 4         | Vietnam is one of the countries heavily affected by natural disasters and climate change.                                                                                            | 1                     | 2            | 3              | 4               | 5                        |
| 5         | Storms and floods are common natural disasters in many localities in Vietnam.                                                                                                        | 1                     | 2            | 3              | 4               | 5                        |
| 6         | Most natural disasters cause significant damage to people, properties, the environment, and socioeconomic activities.                                                                | 1                     | 2            | 3              | 4               | 5                        |
| 7         | The elderly and children are subject to high levels of vulnerability when natural disasters strike.                                                                                  | 1                     | 2            | 3              | 4               | 5                        |
| 8         | Natural disasters happen unexpectedly, but people can contribute to preventing and mitigating damage caused by natural disasters.                                                    | 1                     | 2            | 3              | 4               | 5                        |
| 9         | Disaster prevention is the responsibility of government agencies and individual, including students.                                                                                 | 1                     | 2            | 3              | 4               | 5                        |
| <b>II</b> | <b>Perception</b>                                                                                                                                                                    | <b>Strongly Agree</b> | <b>Agree</b> | <b>Neutral</b> | <b>Disagree</b> | <b>Strongly Disagree</b> |
| 1         | Skills of first aid, treating wounds, swimming, finding safe shelters, and keeping the water clean should be learned and practiced.                                                  | 1                     | 2            | 3              | 4               | 5                        |
| 2         | It is necessary to organize disaster-response drills for all social classes, including students.                                                                                     | 1                     | 2            | 3              | 4               | 5                        |
| 3         | It is necessary to be mentally active and ready to respond to natural disasters.                                                                                                     | 1                     | 2            | 3              | 4               | 5                        |
| 4         | It is necessary to coordinate with family members to make a plan to respond to natural disasters.                                                                                    | 1                     | 2            | 3              | 4               | 5                        |
| 5         | It is necessary to tie up houses and have a plan to protect assets before a disaster strikes.                                                                                        | 1                     | 2            | 3              | 4               | 5                        |
| 6         | When a natural disaster is about to strike, it is necessary to prepare food and essential items, clean water, and medical equipment which are enough to use for at least seven days. | 1                     | 2            | 3              | 4               | 5                        |
| 7         | It is necessary to keep up to date with disaster warnings through the media.                                                                                                         | 1                     | 2            | 3              | 4               | 5                        |
| 8         | It is necessary to follow the disaster-response guidelines of the local government through the media.                                                                                | 1                     | 2            | 3              | 4               | 5                        |
| 9         | It is necessary to keep important phone numbers and contacts in case of emergency.                                                                                                   | 1                     | 2            | 3              | 4               | 5                        |

Table A1. Cont.

| No. | Statement                                                                                                                                                                                                      | Level of Agreement |       |         |          |                   |
|-----|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|-------|---------|----------|-------------------|
| 10  | It is necessary to learn the emergency evacuation routes that may need to be used in the event of a disaster.                                                                                                  | 1                  | 2     | 3       | 4        | 5                 |
| 11  | It is necessary to stay in a house or a solid, safe area when a disaster strikes.                                                                                                                              | 1                  | 2     | 3       | 4        | 5                 |
| 12  | Electrical appliances need to be unplugged during a disaster.                                                                                                                                                  | 1                  | 2     | 3       | 4        | 5                 |
| 13  | It is necessary to keep up to date with the disaster situation through the media.                                                                                                                              | 1                  | 2     | 3       | 4        | 5                 |
| 14  | It is necessary to call emergency phone numbers immediately when in danger in a disaster.                                                                                                                      | 1                  | 2     | 3       | 4        | 5                 |
| 15  | It is necessary to evacuate with family to a safe place when feeling unsafe in the disaster.                                                                                                                   | 1                  | 2     | 3       | 4        | 5                 |
| 16  | In case of flooding, when moving, it is necessary to use life jackets or other floating objects.                                                                                                               | 1                  | 2     | 3       | 4        | 5                 |
| 17  | Attention should be paid to the protection of the weak elderly, children, and people with disabilities in the event of natural disasters.                                                                      | 1                  | 2     | 3       | 4        | 5                 |
| 18  | It is necessary to strictly follow the direction of the relevant authority or the local government where the disaster occurs.                                                                                  | 1                  | 2     | 3       | 4        | 5                 |
| III | Skills                                                                                                                                                                                                         | Strongly Agree     | Agree | Neutral | Disagree | Strongly Disagree |
| 1   | I am aware of the natural disasters that may occur in the area where I live.                                                                                                                                   | 1                  | 2     | 3       | 4        | 5                 |
| 2   | I can find and track disaster-related information.                                                                                                                                                             | 1                  | 2     | 3       | 4        | 5                 |
| 3   | I can coordinate and assign work with family members to respond to natural disasters.                                                                                                                          | 1                  | 2     | 3       | 4        | 5                 |
| 4   | I know what necessities and essentials need to be prepared before a disaster strikes.                                                                                                                          | 1                  | 2     | 3       | 4        | 5                 |
| 5   | I can give first aid to injuries caused by natural disasters.                                                                                                                                                  | 1                  | 2     | 3       | 4        | 5                 |
| 6   | I know of places or channels of communication that can help my family and me when in danger of a natural disaster.                                                                                             | 1                  | 2     | 3       | 4        | 5                 |
| 7   | I am willing to join my family, school, and neighbors to participate in disaster-prevention activities such as pruning trees, bracing houses, protecting assets, and preparing emergency bags and necessities. | 1                  | 2     | 3       | 4        | 5                 |
| 8   | I am willing to join my family, school, and the residents in my neighborhood to participate in cleaning activities to overcome consequences after natural disasters.                                           | 1                  | 2     | 3       | 4        | 5                 |
| 9   | I am willing to participate in voluntary activities to help the community to overcome the consequences of natural disasters.                                                                                   | 1                  | 2     | 3       | 4        | 5                 |
| 10  | I can disseminate knowledge, skills, and experience in disaster prevention to everyone.                                                                                                                        | 1                  | 2     | 3       | 4        | 5                 |

**Table A2.** Below are activities to help children learn disaster prevention skills. Could you please tell us the implementation level of these activities?

| IV | Activities                                                                                                         | Never | Rarely | Sometimes | Usually | Always |
|----|--------------------------------------------------------------------------------------------------------------------|-------|--------|-----------|---------|--------|
| 1  | I receive disaster prevention education at school.                                                                 | 1     | 2      | 3         | 4       | 5      |
| 2  | I receive disaster prevention education through related subjects.                                                  | 1     | 2      | 3         | 4       | 5      |
| 3  | I am educated about disaster prevention through propaganda and experiential activities organized by schools.       | 1     | 2      | 3         | 4       | 5      |
| 4  | I receive disaster prevention education through books, documents, and information provided by teachers or schools. | 1     | 2      | 3         | 4       | 5      |
| 5  | I receive disaster prevention education through the Internet, TV, newspapers, radio, social networks.              | 1     | 2      | 3         | 4       | 5      |
| 6  | I am educated about disaster prevention through discussions with relatives and friends.                            | 1     | 2      | 3         | 4       | 5      |
| 7  | I am educated about disaster prevention through local propaganda activities.                                       | 1     | 2      | 3         | 4       | 5      |

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## Article

# Sustainable Language Training for Engineering Students: Integrating Resource-Efficiency into the Course Content through the Educational Process

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**Abstract:** The sustainable use of the Earth's resources is recognized as increasingly important on a global scale, especially in relation to natural resource management, and is effectively addressed under the auspices of resource efficiency within engineering education. This has led to an increased demand for engineers able to carry out professional activities whilst considering sustainable issues, as well as adopting state-of-the-art technologies, and applying the best domestic and foreign practices. The study of resource efficiency encompasses a range of aspects, from natural resources, through information management, technological tools, time, and other resources. Effective engineering education should include resource efficiency, whilst enabling students to become autonomous lifelong learners, and to develop as potential researchers and professionals, able to take account of emerging issues and approaches for resource efficiency. This paper begins by analyzing the concept of resource efficiency and key research in this area. It goes on to provide a framework to demonstrate how resource-efficiency can be delivered as part of the teaching of year one engineering students, with a theoretical and methodological scaffolding. The paper presents a case study which utilizes resource efficiency within language training. The paper defines the notion of language training resources and their classification. The case study demonstrates the feasibility of the proposed approach and includes a formal assessment to show its effectiveness.

**Keywords:** sustainability; resource-efficiency; personal engagement; professionalization; autonomization



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## 1. Introduction

### 1.1. Resource-Efficiency and Sustainability: Motivation and Background

Sustainable Development and the associated Sustainable Development Resource-efficiency (RE) can have an impact on almost any sphere of human life and work, enabling a sustainable approach for human activities that is recognized as increasingly important [1].

Sustainability was recognized internationally in late 1960s and early 1970s, with Sustainable Development as a concept being the focus in 1972 of a Stockholm UN conference.

This was a key focus for the Brundtland Commission report in 1987 on “Our Common Future”, and a major part of a United National summit in 1992 in Rio de Janeiro, which developed a response to Brundtland. In 2002, an international summit on SD developed initiatives to support SD globally, including “Education for Sustainable Development” (ESD). In 2012, this developed into the Sustainable Development Goals (SDG), and in 2015, all of the UN member states adopted the “2030 agenda for Sustainable Development” with the goals at the heart of the action. Whilst this context is helpful, it also highlights the challenges, as economic and global pressures mean that the commitments to SD are under threat as countries prioritize other policy issues. The recognition of SD within countries also varies, and resource efficiency can have a higher standing in some contexts as it provides material benefits as well as the broader ethical ones that SD itself seeks to create.

The efficiency of an activity depends on the professional and intellectual characteristics of the practitioner, in particular their outlook and thinking. Following from this, professional education should develop the relevant skills and understanding of the world—their noospheric mentality. This should develop alongside an appreciation of the impact of humankind on the environment, and the need to ensure safety and sustainable/smart resource management of this technosphere [2]. Some employers report that engineering graduates have a low level of understanding of the fundamental concepts of resource efficiency, lacking hands-on experience and awareness of the concepts, relevant international standards, and best practices [3]. The broader subject of sustainable development can be utilized to contextualize and motivate professional behaviors and values, and this encompasses RE as a key aspect for software engineers [4].

Nowadays, there is a high demand for world-class engineers able to demonstrate and apply their competences in accordance with international requirements, considering good practice and approaches to tackle RE problems. Given the international context of this, a high level of academic and professional English is an essential attribute for such specialists. That is why teaching English to future engineers is of particular importance. Even though RE technologies are flourishing and gaining significance worldwide, curricula and teaching materials do not necessarily reflect this. This paper will describe and evaluate a framework for embedding the resource efficiency approach within the language teaching, which has the potential to be applied to other disciplines and teaching.

### *1.2. A Definition of Resource Efficiency*

The term “resource efficiency” originated and is predominantly used in the fields of energy engineering and natural resource management. The etymology of the word “resource” stems from the Old French *ressource*, traced back to the Latin *resurgere* meaning “assistance”. The usage of the word “resource” in Modern English varies from the description of a creative competent person to means and conditions increasing productive capacity of an activity [5]. RE can be considered as a measure of human activity, namely the degree of the efficiency of an activity to affect the maximum possible result with minimum expenses measured as a smart and creative use of a wide range of resources. In terms of management, RE provides a means to manage physical, financial, timing, information, human, and other resources in an effective and responsible manner [6]. It does not mean doing more with less resources and eliminating wastes as lean philosophy suggests [7]. Efficiency is turning wastes into resources [8]. Resource efficiency is directly linked to Sustainable Development, with similar themes and with specific application to several of the Sustainable Development Goals. Thus, RE should be considered in all branches of human activity, and especially in the field of professional education and training of engineers to enable a sustainable economy. RE teaching and learning implies applying a state-of-the-art educational approach to enhance language training, maximizing its quality and efficiency due to the effective use of various resources available in an academic environment [9].

The term “resources” as applied to FLT (foreign language teaching/training) denotes teaching and learning resources in a general sense, with objects (teaching materials, facilities, and devices) and intellectual tools (strategies and ways of learning and communicating). These mechanisms can be divided into primary and secondary, technical, and nontechnical. Some authors interpret educational methods, content, and process as didactic means for goals realization. Indeed, a foreign language represents not only the goal but also the means of learning [10–12].

There are various ways to teach resource efficiency, and to attempt to integrate it within different modules. These should outline the engineering profession; the basics of resource efficiency; types of resources; and effective technical communication [13–15].

## 2. Materials and Methods

### 2.1. Methodology

The approach to this paper is based on a literature review and analysis, to develop a framework to teach resource efficiency. This framework is presented and described in the following section. Having established the framework, the paper presents a case study of its use (Section 3), which provides data to analyze the effectiveness of the framework in practice. The implementation was carried out as action research, collating a mix of quantitative and qualitative data, with questionnaires used to evaluate the framework when applied in practice.

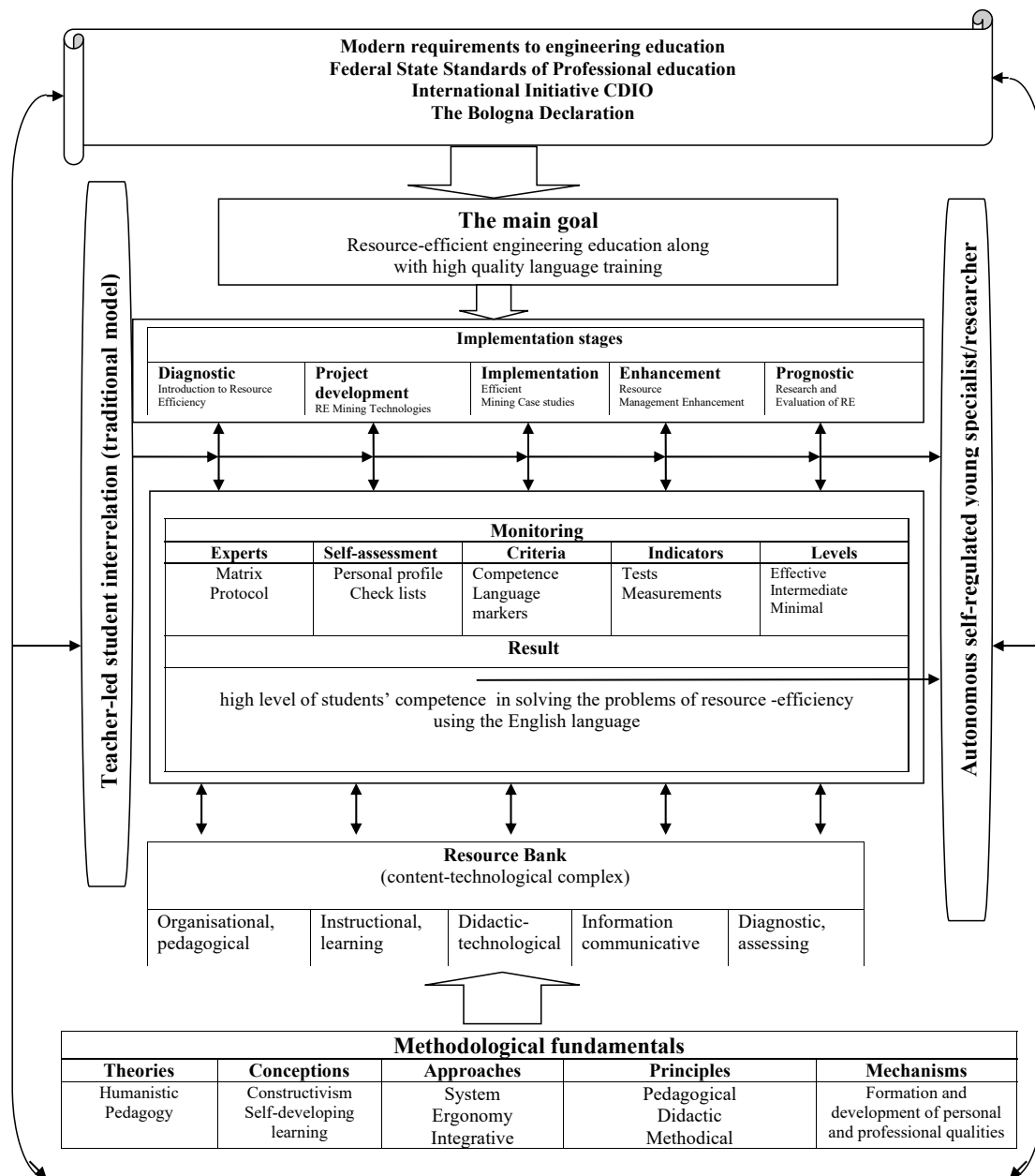
### 2.2. Resource-Efficient English Language Training

The development of the proposed effective professional training methodology is based on a mix of psychological and pedagogical concepts, along with a systems analysis approach. This is described in this section and summarized in Figure 1. This paper presents just a theoretical framework and generalized description of the model developed to assess and monitor the process and results of implementing the author's innovative technology in terms of efficiency of using the resource complex in a sustainable way. The application of this model with a detailed description of experimental research work (with the statistical analysis of exact and verified data) will be presented in another (the next) paper to avoid the conflict of authors' interests and rights. The system analysis considered the interconnections of all main components and resource inputs (technical, financial, timing, information, human, etc.) in professional education. One of our main objectives in developing RE language teaching/training (LTT) is to assess the impact of the educational process component on the qualitative and quantitative characteristics of the results. The analysis considered the educational technology, which consists of users (students and instructors), goals and learning objectives, the academic content and organization of the educational process, the methods and means of teaching, the intended results, and their measurement criteria. Such technologies must be effective, manageable, and reproducible. The science-based technologies included the psychological, pedagogical, didactic, and methodical procedures of reciprocity among education members. The technologies are combined with innovative intellectual resources (e.g., multifunctional trainings, heuristic discussions, professional and imitation modeling, etc.) [16,17]. In summary, our approach to teaching resource efficient language learning is based upon the following principal ideas:

- Efficiency of students' self-education and creativity, and their readiness to take responsibility for extracurricular autonomous learning;
- The stage wise transition from an outer instruction of educational process to students' self-management;
- The continuity of monitoring, feedback, and correction, including students' self-control and self-correction;
- Individualization, reciprocal design of personal educational strategies;
- The wide range of educational content and its interpretation;
- Development of academic and professional communication, integration into international educational and professional environments, e.g., teleconferencing, enabling academic mobility, activities such as grant applications and publications;
- Effective use and development of information tools, with intelligent multimedia programs and systems, expert systems, training facilities, and other resources providing high levels of engineering competence and productive efficiency.

There are language, linguo-didactic, and autodidactic means and resources methodized in scientific research works. The language means include lexis and grammar, text and discourse, communication acts, etc. Technical tools, teaching materials, task systems, and methodical instructions are classified as linguo-didactic means. As for autodidactic language learning resources, this category is booming and gaining popularity among learners due to the expansion of information and communication technology. "Resources" are

commonly associated with ICT, web content, online education courses, virtual learning environments, etc.



**Figure 1.** Resource-Efficient second/foreign Language Training (RELT).

Based on the above, we define the term “language training resources” as a specially developed combination of methodical means, materials, and technologies underpinned by the goal and system of developing students as highly effective world-class engineering specialists. The RE technology of language training is based on the principles of engineering pedagogy, the CDIO Initiative, and in accordance with guidelines of international engineering associations, and the International Society for Engineering Education that accredit educational programs at TPU aimed at preparing elite engineering specialists, all of which include our language training course with the framework and technology especially designed and tailored with sustainability and resource efficiency in mind; these two concepts being most in demand for tackling urgent worldwide problems requiring engineers to solve them. The key aim of language training is to form students’ experience of successful

resource management while solving academic and professional problems. Thereafter, they are gradually involved in creating their own resources (didactical, informational, communicative, technological, etc.) and designing personal learning pathways/environments to provide the quality of language training and competitive performance throughout their engineering career. In fact, it is the efficient use of methodized resources that optimizes the language training and turns it into an innovative technology in its own right. The optimized choice of didactic mechanisms, along with a rational combination of educational formats is the basic principle that allows us to enhance English language training, whilst minimizing the waste of resources.

From a literature review, collating ideas from several approaches [18–20], we have defined a system of interrelated resource groups (along with social, technological, timing, etc.), namely: education-instructional (teaching materials), didactic-technological (methods, strategies), info-communicative (links, discourse types, information channels), control-diagnostic (reports, evaluation sheets, check-papers, measurement protocols and procedures), pedagogical (conditions, processes, management, involvement, design, monitoring, and other procedures).

Resource-efficient language training implies learner autonomization and LTT syllabus professionalization on the basis of an integrative-synergetic approach that allows us to bring together the capacities of more productive up-to-date scientific theories and technologies (competence and personality developing, PBL, heuristic, ergonomics, ICT, reciprocal, etc.). Syllabus professionalization is achieved through the use of specialized work-related materials, tasks, and procedures (cases, projects, reports, meetings, workshops, discussions, conferences, etc.), which help to create a profession-oriented environment [21,22].

Learner autonomization [23] takes place when students gradually (stagewise with the instructor's support and assistance) acquire the skills and qualities of an experienced learner and independent language user capable of using English for solving professional communicative tasks [24]. This is associated with the increase of learners' resourcefulness [25]), i.e., selection and development of various strategies and resources in cooperation with their language instructors, thus, becoming equipped with a personal toolkit and being able to create their own effective instrumentation/environment to implement meaningful complex projects (academic, professional, communicative, etc.). Being a personality attribute, resourcefulness manifests itself in the efficient use and management of inner (self-potential) and outer resources for personal fulfillment and innovative transformation of the surrounding reality/world. A resourceful learner/student is mobile, constructive, organized, self-efficient, and successful in setting and achieving his goals [26,27].

### 2.3. Assessment and Evaluation of the Framework

RE evaluation procedures must meet the following requirements:

- Application of a variety of diversified assessment methods and procedures, including experts' participation.
- Not only the theoretic knowledge levels of students should be measured, but also their manner of setting and solving tasks as well as the choice of necessary resources.
- Final estimates of RE and FL communicative competence formedness are defined during the experts' discussion and data analysis.

We have considered diverse methods of assessment in human resources based on the best world-leading practices, such as the Delphi method, foresight, strategic session, assessment-center, etc. The definition of qualitative and quantitative criteria for the educational process results and efficiency could be implemented by means of the Pearson method (constructing criterion competence model) and by using Kirkpatrick's model for parametric evaluation of educational process structural components efficiency (methods, materials, stages, etc.).

There are different approaches to the evaluation of educational process efficiency based on separate quality and quantity indicators of teaching methods, didactic materials, results, etc. [28]. Considering various evaluation techniques, we developed a diagnostic

approach, allowing us to combine different types of assessment (psychopedagogical, expert, reciprocal and self-control, portfolio, computerized, etc.). The overall value of educational process quality and RE of LTT technology are estimated by means of a generic parameter-oriented arithmetic model.

RE of the above-described technology is evaluated by comparing several measures using our own generalized arithmetic model. The term “measures” refers to the variables and parameters used to describe the model, these are, for example: *Integral measures include the knowledge acquisition volume  $V$  and acquired skills level  $L$ ...* using the following parameters: normative educational time period  $t_{\text{norm}}$ ; limitative time expenditures  $t_{\text{lim}}$ ; three pairs of vectors  $V_0, L_0$ ... measure of a random variable and a mean-square deviation is a dispersion measure, etc. Integral measures include the knowledge acquisition volume  $V$  and acquired skills level  $L$ . It must be noted that due to the diversity of skills and competencies, the  $V$  and  $L$  vectors should be analyzed as a whole and by the components. As we have mentioned, there is a variety of resources, but timing  $t$  and material  $m$  resources have a universal character. Timing and material resources are considered to have an unambiguous correspondence. However, formalization of this correspondence in the context of educational technology could be implemented considering all the studied process components and the resources used.

The efficiency of the technology is estimated through the analysis of the time dependences  $V(t)$  and  $L(t)$ , as well as an acquisition rate/degree  $\frac{dV(t)}{dt}$  and skills development rate/degree  $\frac{dL(t)}{dt}$ .

The arithmetic model for the quality and RE evaluation is defined using the following parameters: normative educational time period  $t_{\text{norm}}$ ; limitative time expenditures  $t_{\text{lim}}$ ; three pairs of vectors  $V_0, L_0$  (vectors of initial knowledge volumes and competence levels),  $V_{\text{lim}}, L_{\text{lim}}$  (vectors of minimally achievable knowledge volumes and competence levels), and  $V_{\infty}, L_{\infty}$  (vectors of minimal remnant knowledge volumes and competence levels). The components of  $V$  and  $L$  vectors achieved during the time  $t_{\text{lim}}$  must satisfy the system of inequalities

$$\begin{cases} V_i(t_{\text{lim}}) > V_{\text{lim } i}, & i = 1 \dots n; & L_j(t_{\text{lim}}) > L_{\text{lim } j}, & j = 1 \dots m \\ V_i(t) > V_{\infty i}, & i = 1 \dots n; & L_j(t) > V_{\infty j}, & j = 1 \dots m, & t \gg t_{\text{lim}}, \end{cases} \quad (1)$$

where  $n$  and  $m$  represent the number of components in the vectors of knowledge volume and competence levels, respectively.  $(i)$  and  $(j)$  are indexes corresponding to certain components of the vectors of the knowledge acquisition volume  $V$  and acquired skills level  $L$ .

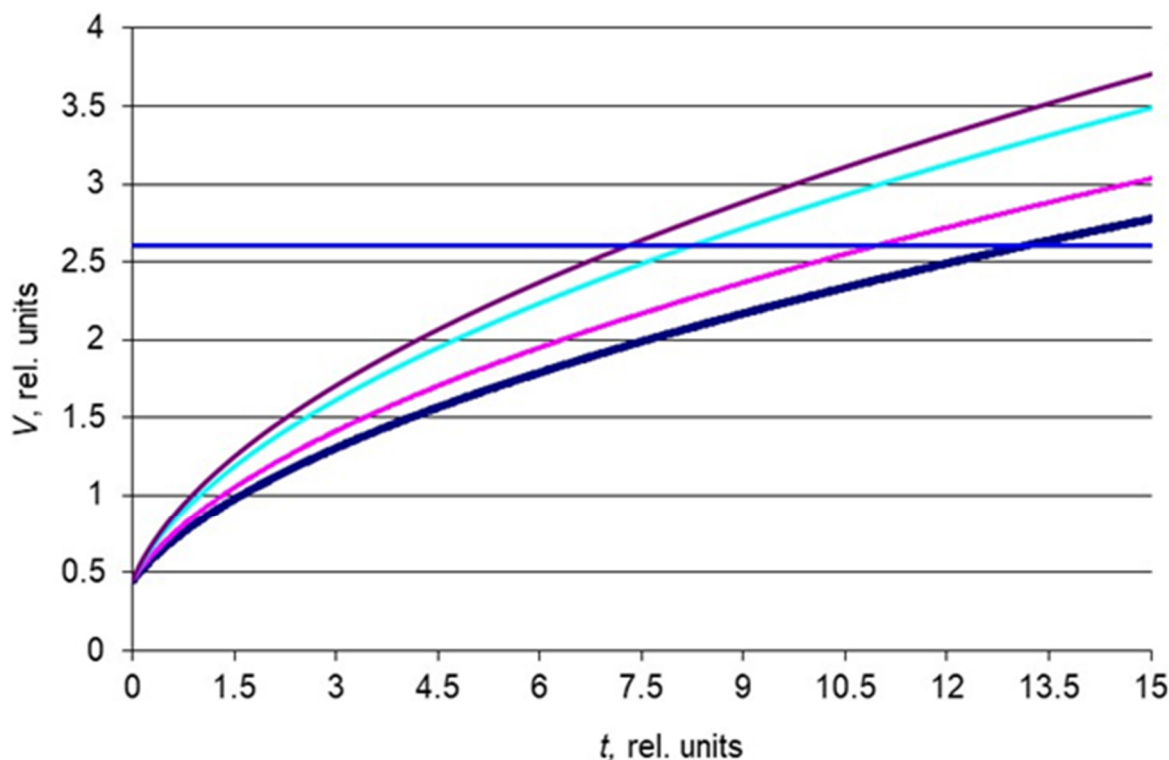
Additional limitations for the technology are associated with the prevalence of retention over forgetting.

$$\frac{dV_i(t)}{dt} \geq \alpha_i, \quad i = 1 \dots n \quad \frac{dL_j(t)}{dt} \geq \beta_j, \quad j = 1 \dots m$$

where  $\alpha_i$  and  $\beta_j$  are the prevalence coefficients. The technology must ensure the inequalities  $\alpha_i > 0$  and  $\beta_j > 0$ . These inequalities hold for monotonic increasing functions  $V_i(t)$ ,  $i = 1 \dots n$  and  $L_j(t)$ ,  $j = 1 \dots m$ . The higher the values of these coefficients, the more efficient the analyzed educational technology.

To illustrate this, the qualitative integral dependences  $V(t)$  for different technologies are given in Figure 2. The dependences 1–4 are for the same educational process duration  $t_{\text{norm}}$  and similar basic levels of knowledge and competences  $V_0$ .

A minimum integral index of knowledge volume and competence level  $t_{\text{lim}}$  is marked on Figure 2, which is determined by the results of pilot tests.



**Figure 2.** Qualitative integral dependences  $V(t)$ : 0—required level  $V_{lim}$ ; 1—low RE level; 2—intermediate RE level; 3—advanced RE level; 4—high RE level.

**Remark 1.** The components of the investigated vectors-functions must be continuous but not necessarily smooth. This is since the usage of certain resources might be separated by the time intervals, and, furthermore, the intensity of pedagogical interventions and students' reactions to them are different for these resources. For instance, total language immersion dramatically intensifies the learning process.

**Remark 2.** Students differ by their learning abilities, initial knowledge volumes, and competence levels, so strictly speaking, vectors-functions are random. The vectors and other parameters are random and expressed in letters because this is a generalized description and presentation of our model. However, when it comes to application of this model, we use strictly verified data. This makes it necessary to consider the main parameters of random variable  $V_i(t)$ ,  $i = 1 \dots n$  and  $L_j(t)$ ,  $j = 1 \dots m$  at an arbitrary point in time. The mean value is the position measure of a random variable, and a mean-square deviation is a dispersion measure. The mean values of integral dependences are given in Figure 3. An absolute continuity of the learning process monitoring is not realistic. However, in order to compare educational technologies, the estimation of mean values and the relevant mean-square deviations  $\overline{V_i(t)}$ ,  $\sigma V_i(t)$ ,  $i = 1 \dots n$  and  $\overline{L_j(t)}$ ,  $\sigma L_j(t)$ ,  $j = 1 \dots m$  must be carried out quite often. It is necessary for a timely correction of the pedagogical intervention form and intensity, as well as resources being applied.

**Remark 3.** The two characteristics of the analyzed random variables may not be sufficient. A more complete characteristic feature of a random variable is its frequency distribution. However, a small number of participants in pedagogical experiments does not allow determining random frequency distribution to high precision. Sample distribution functions of the analyzed random values make it possible to implement multifactor monitoring of the educational process with a higher precision.

To illustrate remark 2, an optimistic scenario and a pessimistic scenario of an educational process development are shown in Figure 3, with the estimation  $f$  of a sample relative distribution function/frequency  $Q_k$ . The latter is a  $k$ -stage assessment, which could

be measured on a 100-score scale. The evaluations of all stages characterize the quality of achieving goals against a unified scale along with the sequential tests  $t_k$ ,  $k = 0 \dots k_0$  connected with the discrete values of  $V(t_k)$  parameter.  $k = 0$  corresponds to the initial (diagnostic) stage of testing students at the beginning of the course.  $k = k_0$  is the final knowledge and competence testing procedure. There's  $k_0 = 3$  in the example. Diagnostic testing is aimed at dividing students into groups with relatively similar levels of knowledge.

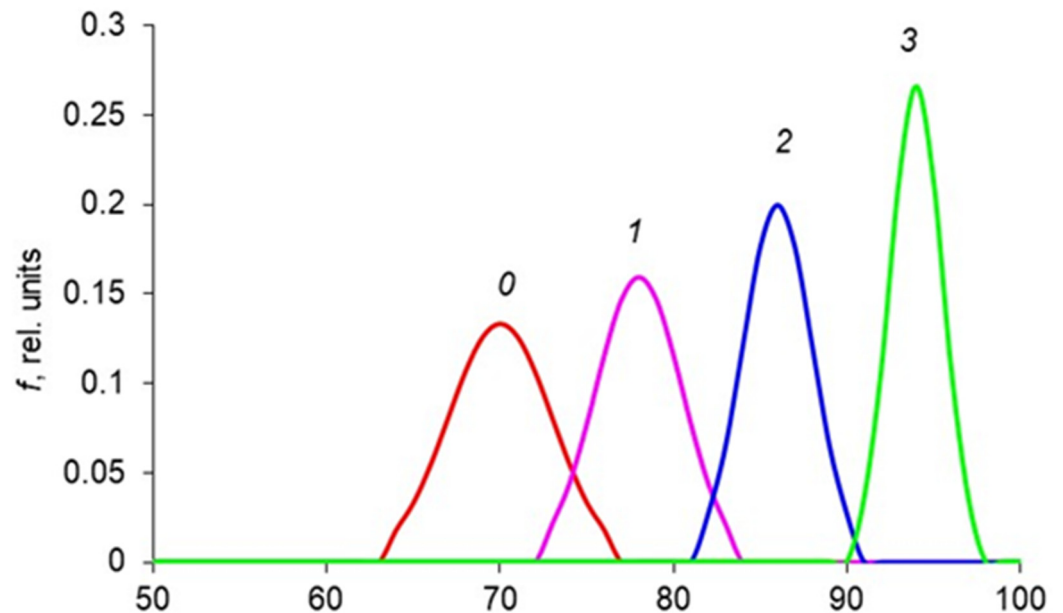


Figure 3. Optimistic modelling of educational process development.

Figures 3 and 4 show the versions of an educational process development: *a*—optimistic, and *b*—pessimistic. The shifting of the mean value and the narrowing of distribution density in the optimistic version indicates the increasing knowledge and similarity levels in experimental groups.

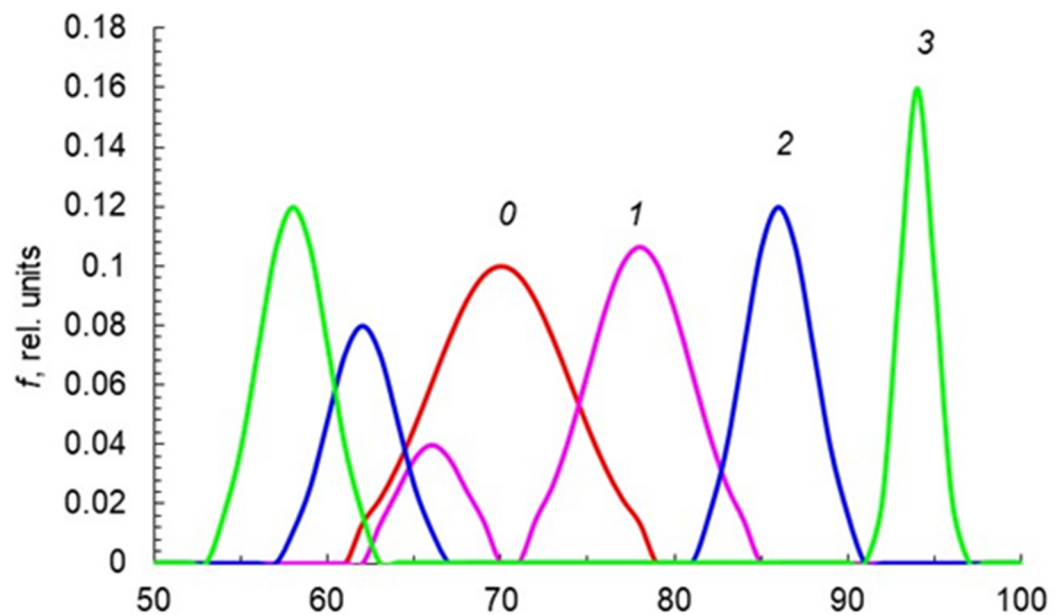


Figure 4. Pessimistic model of educational process development.

Unimodal distribution density is turning into bimodal function with significantly spaced-apart modes in the pessimistic version, which means that the knowledge level is becoming diversified.  $Q$  is an essential model parameter for comparing educational technologies at the final stage of the course. If this parameter is lower than a certain limit level  $Q_{\text{lim}}$  for the student, he/she fails to graduate, and the educational resources spend on his/her training were used inefficiently.

**Remark 4.** *Additional criteria to compare educational technologies are associated with long-term changes in the knowledge and competence levels. The technology under study will be more efficient if the component means of vectors  $V_{\infty}$ ,  $L_{\infty}$  exceed those of the conventional education technology. The above-mentioned changes essentially depend on external conditions, with the main one being the presence/absence of motivation for life-long autonomous language studies. An education technology that inspires students to become a life-long language learners is obviously the more efficient one. It should be stressed, here, that a continuous profound monitoring of the educational process allows evaluating the goal adequacy of methods being applied, as well as to consider the individual student's needs and take measures for correction of pedagogical interventions.*

**Remark 5.** *The above-described approach is considered worthwhile on condition that all material resources are equal in monetary equivalents. It is also necessary to consider the cost of a highly qualified specialist in relation to the real demand for him at the regional and international trade markets.*

### 3. Case Study

#### 3.1. The Challenge of Teaching Resource Efficiency

Whilst we have identified in Section 1 the importance of RE, in our experience this topic is not always well integrated within the training of engineering students. Given the importance of the topic, our research focusses on developing an approach for RE education within language teaching of engineering students, to help them acquire competence and experience in successful RE problem solving in their academic and professional activities as regards the development of their English language skills. The current work is novel in that it studies RE from multiple perspectives in the context of foreign language training of engineering students. RE is an essential component of the syllabus, i.e., RE and Smart Resource Management represent the content of the language training.

In order to include RE into the content of the language training program, we structured it in the following way. During the first and second terms, students acquire a general understanding of various resource types and learn to appreciate the necessity of using them in a smart way. Students are introduced to a wide range of language learning approaches and tasks, including video presentations, webinars, and workshops on appropriate topics, encompassing: the engineering profession; the basics of resource efficiency; types of resources; and effective technical communication [13–15].

The basic principle of this stage is learning through action and participation in interactive events, which involve students researching different approaches to solve RE problems while using a Foreign Language (FL). Second year students study professionally oriented cases and accomplish scientific projects arranged in the following topics: Engineering Education around the World, Resource Efficient Technologies in Russia and Abroad, Rational Choice of Prospecting and Exploration Techniques, Safety and Effectiveness of Operations, Resource Management Enhancement, Resource Efficiency Research and Evaluation Methods.

The results of students' research project work are presented at conferences to undergo review by experts. Based on their research work, students prepare grant proposals, professional reports, and scientific articles in English, in cooperation with their supervisors. The best articles are chosen to be published in conference proceedings indexed, such as the annual International Scientific Symposium "Problems of Geology and Subsurface Development", the annual Scientific Conference "Youth Energy to Resource Efficient Technology",

and Young Engineers Summit, International Conference “Resource Efficient Systems in Management and Control”.

This work took place at the National Research Tomsk Polytechnic University. The pilot experiment was based on a series of interviews and questionnaire surveys with 68 staff and 200 students, utilizing convenience sampling. This followed the ethical procedures and customs and practices of the host institution. In particular, all participation was voluntary. The process included explaining the goal, tasks, and planned procedure, and to invite students/colleagues to join. The results from the sample informed the design of the framework, and the scoring. The case study based on this involved 35 first year students, who were selected and distributed into two control ( $n = 24$ ) and one experimental ( $n = 11$ ) groups so that their academic performance and their level of knowledge of RE were similar. As described in Section 3.3, RELT was initially launched in 2012. The current work began with the pilot work in 2018–2019, with the main experimental work conducted in 2019–2020. This paper provides the initial outcomes of that to illustrate the framework, with further details in future work.

Our main objective here was to check if the proposed RELT technology seems to meet the requirements of efficiency and sustainability (along with the technological and methodological criteria) and if it achieves the target results. The traditional LT does not employ the system of all required educational resources and lacks the necessary technology and methodology that satisfy the crucial principles of sustainable and resource-efficient training of modern in-demand engineers who will be competent and experienced in solving urgent worldwide problems in collaboration with their foreign colleagues. Thus, it was also necessary to define the complex of pedagogical conditions facilitating the implementation of the innovative technology and conversion of the traditional process of language training, which failed to provide the proper environment for students to acquire the demanded profession-oriented FL skills and competences.

### 3.2. Resource-Efficiency at Tomsk Polytechnic University

Tomsk Polytechnic University is among the first universities to approve an RE development program, which includes the following clusters:

- Safe environment;
- Sustainable energy;
- Medical engineering;
- Planet resources;
- Cognitive systems and telecommunication;
- Social and humanitarian technologies of engineering.

A Smart Grids center and an RE Methodology Lab were created to enable and encourage in-depth research of RE phenomenon. Furthermore, RE has been included into the syllabus at Tomsk, for example, with the course “Fundamentals of RE”, aimed at developing the following graduates’ competences [10]:

- System knowledge about the main types of resources;
- Deep understanding of the necessity to enhance the efficiency of natural resource usage;
- Readiness to solve RE problems in professional, social, and personal life;
- Ability to use the methods for evaluation of resource usage efficiency and analysis of resource life cycle;
- Ability to determine the ways of RE enhancement; ability to use the main methods of RE management in line with the ethical and legislative regulations.

One of the most important conditions for RELT technology realization is a stage wise transformation of the traditional teaching framework into a professional businesslike partnership/collaboration. Traditional teaching implies a “teacher–learner” model/relation with the outer absolute pedagogical control of the whole educational process. The professional businesslike partnership/collaboration is a gradual transition to a reciprocal educational environment with an “advisor–trainee/young researcher” collaboration, the

latter being more self-governed/autonomous [27]. During such collaboration, students are involved in setting and solving meaningful professional and personal RE problems in communicative research projects while learning and using the English language.

Scientists [29] define the following types of students' engagement:

- Academic/cognitive (learning activity, achievements).
- Social/behavioral (participation in extracurricular university activities).
- Emotional/affective (attitude to the university, institutional culture).

We believe that all types of engagement should enrich students innovative engineering attributes (resource-efficiency, functionality, creativity [30]). The degree of students' involvement is associated with their autonomy level. This level is increasing as students gain their problem-solving experience and adopt personal-subjective functions in the process of professionalization and self-actualization. These functions and strategies include goal setting, prioritizing, decision-making, self-motivation, self-management, etc. We now describe the stages of Resource Efficient Second Language Training (RELT).

### 3.3. *The Stages of Resource Efficient Second Language Training*

The course of RELT lasts four semesters, the program is intended to train the first and the second-year students. It was first accepted in 2012 and has undergone five editions since then, but the most profound edition and upgrade began in the 2019–2020 academic session. With the data now collated, we will complete the assessment and evaluation of our innovative technology using the arithmetic model and an advanced expert analysis as described in this paper.

#### I. **Motivational-diagnostic stage**

The main objectives are:

- Diagnostics and evaluation of students' motives, attitudes, their levels of communicative competence and language proficiency;
- Formation of students' motivational readiness to master professional communicative competences;
- Formation of profession-oriented attitudes, notions, and standards of RE in academic, research, and communicative engineering activities.

During this stage, students are introduced to different types of resources and to the ways of using them efficiently. Didactic-informational resources are display materials, showcases, and models. Diagnostic resources include tests, questionnaires, and assessment sheets. Organizational—self-presentations, interviews, trainings, workshops, etc. Info-communicational—forums, chats, blogs, platforms, mobile and Internet tools and apps, etc. Technological means—didactic, learning, and teaching materials. The main results of this stage are the awareness of students' personal learning styles, personalized resource toolbox, individual competence protocols, high motivation, and interest to achieve success in further project work.

#### II. **Project development stage**

The main objectives at this stage are:

- Goal setting and specification of individual learners' needs, objectives, language training expectations;
- Preparing individual learning pathways, self-study programs, schedules, completion of documents;
- Development of self-management and project work skills as the basis for RE in profession-oriented FL communication, academic, and research work.

During this stage, all the above-mentioned types of resources are used as well. Students are engaged in formation of their personal resource toolbox/collection, and they start working with their registers, templates, portfolio, and project documentation. The main results achieved at this point are that students become aware of the new academic settings

and requirements, and they know their goals and are equipped to reach them within a certain time period.

### III. Implementation stage

The main objectives are to ensure the attainment and maintenance of high levels of students' motivation and RE, whilst putting into practice their plans and projects (tackling complex problems and tasks, overcoming challenges, etc.). This is done through:

- Formation of a profession-like environment (professionalization);
- Students' autonomization in the process of learning and using English while tackling meaningful problems and tasks;
- Development of FL communicative competence components (discourse, linguistic, strategic, professional, sociocultural).

At this stage, students may use all available resources, but they are encouraged and helped to create their own (individually or in teams, based on the best examples). The main results—students develop their own RE learning and work understanding and techniques through gaining practical experience.

### IV. Enhancement stage

The main objectives of this stage are to enable:

- Assessment and evaluation, collecting data, analysis of the main outcomes;
- Uncovering mishaps, carrying out correction, improvement of organizational, management and monitoring procedures;
- Adjustment of educational, technological processes in line with the results of RE indicators;
- Development of compensative and regulative mechanisms in communicative competence realization.

The resources used at this stage are mostly diagnostic during the initial phase but in order to implement enhancement measures all other available means and instrumentation are also applicable. The main result—self-efficacy and satisfaction of students with achievements and accomplishments.

### V. Prognostic stage

The main objective—further planning and setting long-term goals, defining anticipated outcomes. By this stage, students have gained the necessary experience, which allows them to sort out their own resources to identify their needs, meaningful tasks, and overcome challenges effectively and autonomously or with a minimal teacher support. The main result is that students are becoming “teachers” for themselves and peers, sharing their best practices, giving feedback and support, assessing, and commenting on the work of their groupmates. Having completed the full cycle, students acquire “the orientation framework” (P. Galperin) for their future activities, they become self-confident (due to their successful achievement experience) and aware of reachable academic career perspectives.

The stages [31] were defined in accordance with the theory of developmental learning and activity orientation framework (developed by P. Galperin in collaboration with L. Vygotsky), which aims at forming learner autonomy, engagement, creativity, and resourcefulness (crucial RE competence components).

### 3.4. Empirical Results and Discussion

The following results were obtained from the above implementation (Section 3). The results from the pilot study showed:

- In total, 72% of the respondents (all) stated that the majority of students lack efficiency in their academic and scientific activities;
- In total, 88% of the lecturers claimed that students should be specially trained to make the right use of available resources (create new ones) and apply them to solve meaningful problems, achieve results, and organize their learning in a sustainable way;

- In total, 79% of students pointed out that pedagogical support, control, and regulation provide the effectiveness of the educational process;
- Agency, responsible attitude, and the ability to avoid distractors were marked as the main attributes for a resource-efficient learner;
- In total, 93% of the participants (all) agreed that there should be a more systematic approach to the development of a structured digitalized resource base with clear instructions, engagement features, and functions for customization, information exchange, communication tools, etc.

In order to test the RELT technology, we carried out an educational experiment, which consisted of three phases: ascertaining (preliminary), implementing (realization of RELT technology), and summative. The ascertaining and summative phases lasted for one month each when measurement procedures, data collection, and analysis were accomplished. The implementing phase, when the RELT technology was introduced into the educational process at NR TPU, lasted for three terms in 2019–2020.

Our preliminary assessment showed that of the 35 participants, 27 of them had poor knowledge of RE, they were not aware of the range of available resources and could not choose and apply the right ones to effectively solve meaningful problems (academic, scientific, communicative, profession-oriented, etc.). Only nine students could effectively cope with the suggested tasks at the minimal RE level. The focus of this paper is the framework itself, and future work will expand on the experimental activities and data.

With the help and support of the experts from Academic Results Assessment Centre at TPU who checked and approved the validity and the fairness of measurements, we calculated the RE index before and after the implementing phase of our experiment. The data were obtained and combined from different sources (students' self-evaluation sheets, experts' protocols, teachers' continuous/final assessments) in the course of students' profession-oriented academic project work, which clearly demonstrated their efficiency to choose/create and apply the range of available resources while solving various problems in a sustainable way using/practicing the English language.

Empirical evidence from the authors using the framework indicate that the RELT technology was viable and effective in developing students' competences and that it was necessary in order for them to have the capacity to carry out resource-efficient and sustainable engineering activities globally using English.

#### 4. Conclusions and Contribution

In order to address the global challenges of resource-efficient and sustainable nature management, higher engineering education should provide a corresponding environment for students to become competent professionals who meet the modern international requirements. Such specialists are highly effective at achieving goals and solving professional problems due to their ability to find, create, and sensibly use various resources.

Thus, based on our theoretical investigation, analysis of practical experience, and experimental work, we assert that the developed technology of professionally oriented training (in the course of technical communication) provides the necessary conditions for students to successfully implement resource efficiency in solving complex engineering problems and lifelong self-education with the use of the English language. A key contribution here is the framework in Figure 1, which provides an approach to teach resource efficiency within language teaching.

Furthermore, considering the variability and universal character of its constituents, the presented technology may also be used to train students in higher educational establishments and institutions of different study fields. It should be stressed here that a continuous profound monitoring of the educational process allows evaluating the goal adequacy of methods being applied, as well as to consider individual students' needs and take measures for correcting pedagogical interventions.

There are researchers who argue that RE could be enhanced drastically through total student immersion and involvement through edutainment technology and gamification of

the educational process [3]. Others suggest diverse communicative practices and internationalization [3,8,32] in order to improve the professional training in terms of its efficiency. In fact, when it comes to scientific research and practical application of resource efficiency, too many aspects and factors arise that could be rather influential. As for the present study, the limitations include the subject area of the higher professional education (it was not an interdisciplinary research) and the lack of feedback from companies/organizations who are among the stakeholders. We are planning our further research developments and RELT technology improvements, taking into consideration the above-mentioned limitations and welcoming other scientific opinions.

**Limitations.** This paper considers one case study in which this approach was used, and there is a lack of control study here. However, the qualitative and quantitative data indicate the potential effectiveness. The approach we have described is considered worthwhile on condition that all material resources are equal in monetary equivalents. It is also necessary to take into account the cost of a highly qualified specialist in relation to the real demand for him at the regional and international trade markets. The grouping of factors in the framework, such as the motivational-diagnostic stage, aggregates aspects such as motives, attitudes, and proficiency. Future work will explore how far those aspects are independent and involve further applications of the framework and will analyze its impact on students' understanding of resource efficiency, in both language teaching contexts and other subject areas.

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## Article

# School Leadership, Education for Sustainable Development (ESD), and the Impact of the COVID-19 Pandemic: Perspectives of Principals in China, Germany, and the USA

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**Abstract:** We live in times of multiple crises. Climate change, degradation of soils, loss of biodiversity, COVID-19, and the war in Ukraine, to name but a few. School leaders are challenged in many ways to tackle the consequences of these crises, to prepare students for a future that will foreseeably be full of crises too, and to just do their “normal” daily work: to make sure that the school is running successfully in order to help students learn how to read, write, calculate, etc. Education for sustainable development (ESD) is a concept that aims at empowering learners with the knowledge, skills, values, and attitudes to address the interconnected global challenges we are facing. This article reports on a study that seeks to investigate what principals in Germany, China, and the United States do to integrate sustainability and ESD in their schools. It specifically addresses the issue of COVID-19 and its impact on the establishment of ESD.

**Keywords:** education for sustainable development (ESD); school leadership; principals; COVID-19; whole school approach



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## 1. Introduction: School Leadership in Times of Multiple Crises

Scientists have long since warned that we are overusing natural resources and living above the limits of planet earth (“Planetary Boundaries”) [1]. Currently, climate change is most prominently discussed, but other developments, such as loss of biodiversity, are no less important and dangerous [2]. Early in 2020, a new virus began to spread worldwide and caused an unprecedented pandemic with manyfold consequences in societies. In 2022, on top of this, new crises developed: the illegal war of aggression against Ukraine provoked migration within and out of Ukraine, resulting in a hunger crisis in the global south, a gas and energy crisis in Europe, and severe damage to international cooperation.

These crises are interdependent and mutually reinforcing. Climate change, for example, destroys fertile soils and the livelihood of people in many countries [3] and thus leads to hunger. In 2021, as a consequence of the COVID-19 pandemic, the global number of people suffering from hunger rose to as many as 828 million, an increase of approximately 46 million since 2020 and 150 million since the outbreak of the COVID-19 pandemic [4]. In 2022, the war in Ukraine further exacerbated the global hunger crisis. Schools are affected by the abovementioned crises in many ways. To prevent the spread of the SARS-CoV-2 virus, since March 2020, schools for more than 168 million children globally have been closed for almost a full year. On average, schools have been closed for 95 instruction days [5]. More than 24 million learners, from pre-primary to university levels, are at risk of not returning to school [6]. In Germany, as of August 2022, more than 150,000 children of Ukrainian refugees are attending classes in schools [7] and need the attention of the school community to be successfully integrated.

School leadership in these times is challenging [8]. During the pandemic, principals had to take extraordinary measures to deal with the health and safety threats caused by the virus; they had to learn new technologies and provide support to teachers in the use of these technologies. School leaders are called upon to respond to emergencies but have not been prepared to manage such crises [9]. However, schools not only have to manage these multiple crises, they need to prepare children for a future that is yet unknown but will predictably be affected by more crises as a consequence of the abovementioned ecological developments and their social effects.

Education for sustainable development (ESD) aims at preparing children for this future. However, how do principals meet the challenge of handling multiple crises that require immediate actions on a day-to-day basis on the one hand and promoting long-term projects such as the implementation of ESD on the other hand—the latter being a responsibility that is not as pressing, but is no less important?

## 2. Goal of the Study

Against this background, our study seeks to explore how principals in China, Germany, and the U.S.A. deal with the implementation of ESD in their schools. Considering the above-described situation of “leadership in crisis”, we are specifically addressing the issue of COVID-19 and its impact on the establishment of ESD.

## 3. State of Research

### 3.1. Sustainable Development (SD) and Education for Sustainable Development (ESD)

During the last three decades, sustainable development (SD) has become a guiding societal value. Since 1992 and the Earth Summit in Rio de Janeiro, it has been the official goal of the majority of nations worldwide. In 2015, the United Nations adopted Agenda 2030, “a plan of action for people, planet and prosperity [ . . . ] to shift the world onto a sustainable and resilient path” [10]. An important part of Agenda 2030 is the 17 sustainable development goals [11], SDGs, which address the most urgent problems of humanity and the planet, such as poverty, hunger, climate change, loss of biodiversity, etc. From the beginning, the agenda and the 17 SDGs have been criticized as being inconsistent and difficult to qualify, implement, and monitor [12]. Yet, Agenda 2030 is the one sustainability effort that is supported worldwide by many states, companies, NGOs, and educational institutions. Unfortunately, the abovementioned latest developments, the COVID-19 pandemic, and the war in Ukraine are menacing to jeopardize Agenda 2030 and SDGs, as revealed by the latest report on the progress of SDGs [13].

“Quality Education” is goal number 4 of the 17 sustainable development goals, but it is also connected to all other goals. Climate change, hunger, injustice, or diseases cannot be cured by education, but for sure, they cannot be cured without education. ESD is one of the subgoals of goal 4. The goals are described as follows: “By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and nonviolence, global citizenship and appreciation of cultural diversity and of culture’s contribution to sustainable development” (“Sustainable Development Goal 4 (SDG 4),” accessed on 15 July 2022). Various UN programs have addressed ESD and aim to push its implementation forward [14–17].

Despite the many efforts of the UN, the current status of ESD, from a world perspective, is still very diverse. There are countries with far-developed ESD activities; others are just beginning. However, within countries, one can also find a huge variety of statuses. Often, there are some schools that are well on the way and others that are far behind. Additionally, most often, singular activities are prevailing, and ESD is not yet structurally anchored within schools.

### 3.2. Sustainable Development (SD) and Education for Sustainable Development (ESD)

Having focused on earlier programs mainly on teaching and learning, in its latest programs, UNESCO also aims to implement changes at the institutional level. One of the five priority fields in “ESD for 2030” is “Transforming learning and training environments”:

“To encourage learners to become change agents who have the knowledge, means, willingness and courage to take transformative action for sustainable development, learning institutions need, themselves, to be transformed. The entire learning institution needs to be aligned with sustainable development principles, so that learning content and its pedagogies are reinforced by the way facilities are managed and how decisions are made within the institution. This Whole Institution Approach to ESD calls for learning environments where learners learn what they live and live what they learn” [17] (p. 28).

In this context, UNESCO now expressively addresses the “Leaders of learning institutions, including school principals, presidents and rectors of universities and colleges, heads of TVET centres and of staff training centres in private companies” as main actors.

“Leadership for ESD” has rarely been the focus of empirical research. Although school effectiveness research has shown that principals have a decisive influence on the quality and the performance of a school [18] and that leadership is the second most important factor related to students’ learning outcomes [19], there is only a small number of studies that have investigated the role of principals in ESD [20].

Several studies point out the important role of the principal in establishing and promoting ESD in Schools [21,22]. Principals must create a shared vision related to ESD within their schools and organize a participative process, emphasize ESD in daily life, support teachers in the application of ESD, and facilitate students’ engagement [23].

Principals appear to be primarily motivated by a personal interest in SD and ESD and in matters that affect the future of their communities [24]. Their motivation may additionally be enhanced by the support they receive from other principals and leadership teams [25]. To create a sustainable school, the principal’s care for and commitment to SD and ESD plays an important role in implementing ESD [26,27]. Principals need several competencies, for example, sufficient knowledge of ESD [28] and an interdisciplinary frame and understanding of ESD [29]. To successfully organize a complex change process, they need strategic and systematic thinking, communication skills, and the ability to address the various stakeholders involved [30].

In many schools, ESD is a matter of projects by individual teachers and limited by a lack of cooperation [28]. It is often uncoordinated, restricted to special occasions, and not an essential component of the school program [29]. However, especially in recent studies, the importance of a holistic concept is highlighted. Following the whole school approach—sometimes also referred to as the whole institution or whole system approach—, ESD must be anchored in structures and processes [31]. Therefore, a participative process of school development must be organized that includes the whole staff and other stakeholders of the school [23].

Some studies identified measures that principals take to establish ESD, such as the development and distribution of a shared vision for ESD, the development of a school program that includes ESD, the appointment of a coordinator for ESD, the institution of committees to tackle ESD matters in the school or extra hours for teachers to implement ESD [23,32,33]. ESD is a collegial effort and requires teamwork [24], as well as corresponding leadership approaches such as distribution of responsibility [25,31], shared leadership [31], and responsible leadership [23].

In one study, several principals pointed out that self-management is required to maintain one’s resources [30]. “Introducing ESD in schools is not a sprint, it’s marathon”, as the authors summarize. To lead their schools and staff, principals must first be able to lead themselves. This includes the principal’s self-awareness and personal beliefs, time management, work–life balance, and personal development.

Principals involved in the studies named several barriers that hinder the process of implementing ESD in schools, e.g., lack of time to appreciate the complexities of ESD [29,34],

shortage of funds [34], or limited examples of good practice regarding leadership for SD and ESD [29]. They also complained about the limited support of ESD by the government and the absence of holistic, systematic, and long-term government policy [34,35].

### 3.3. ESD in China, Germany, and the USA—A Short Overview

There are many differences between China, Germany, and the USA in general, between their respective school systems, and between the status of ESD within the countries [30]. Due to restrictions of place, we can only provide a short overview referring to ESD.

Germany has a long history of environmental education and adopted the concept of ESD early [36,37].

The ESD decade helped to develop structures for ESD and inspired numerous ESD projects [38]. Answering the global action program for ESD (GAP), the German Government adopted the National Action Plan for ESD [39], which led to many activities. ESD and the outcomes of the National Plan are monitored [40,41]. One large-scale study showed that the implementation of ESD has an impact on behavior [42]. One goal of the National Plan was to integrate ESD into many formal documents, e.g., the statewide curricula. This effort succeeded in many cases, but there are big differences between the 16 states [43]. Despite this, ESD is not yet structurally anchored within schools [42].

School leadership and organizational development for ESD were long not within the focus of educational policies and practice in Germany. This changed after the GAP when the whole institution approach became a prominent guideline for ESD [44]. Additionally, the “development, testing, consolidation and dissemination of qualification concepts for leaders” is now a goal within the German Federal Government’s National Action Plan on ESD [39] (p. 43). Regarding research on leadership for ESD, only a few studies explored the field [23,33].

In the United States, several high-level initiatives sought to foster the development of ESD. Responding to the ESD decade, programs were created to raise awareness for ESD and to expand ESD in schools. The GAP accelerated progress towards ESD, but despite many activities, ESD is only just starting to develop in the United States. Monitoring ESD activities on a national and state level is sporadic. Little is known about the role of principals in ESD.

Most ESD research that has focused on teaching and learning has alluded to the importance of the school leader. Indeed, the results of school effectiveness research allow the conclusion that school principals can exert significant influence in this area. Nevertheless, the role and contributions of school leaders in the implementation of sustainability and ESD in schools have rarely been the subject of empirical studies [22,45,46].

In China, the environmental crisis led to more and more environmental policies, starting in the 21st century. ESD is considered an essential area in the new Chinese educational reform. The country answered to the UN decade and the following programs by developing structures and with teaching and learning projects. Environmental issues are integrated into official documents. ESD is still focused on environmental issues and not yet on sustainability in a comprehensive way. The role of school leadership for ESD is not yet the focus.

In mainland China, one notable experience was the large-scale national environmental education (EE) project conducted by three organizations [47]: governmental agencies (The Ministry of Education, PRC), an international non-profit organization (the World Wildlife Fund of China), and an international corporation body (British Petroleum, [short for BP]). The project was planned to be carried out in three phases over a 10-year period, from 1997 to 2007, which aimed to disseminate ESD within the Chinese education system. To hit this target, many approaches have been determined, such as designing a school-based curriculum (including primary and middle school), developing green school projects, promoting ESD in the community, and addressing research on ESD in higher educational institutions [48].

Regulations of Beijing in 2020 also emphasized that the knowledge of garbage classification in all schools should reach 100%. Chaoyang District of Beijing proposed a “1 + 6 0 + N” strategy to promote the regulations [49], where 1 refers to garbage classification action, 60 refers to the current national experimental schools of Education for Sustainable Development in Chaoyang District, the successful/model schools designated by the China National Working Committee for UNESCO on ESD, and N refers to all schools, preschools, primary school, junior high schools, senior high schools, and vocational schools. The 60 model schools play a leading role in garbage classification and then share their experiences with all schools in the district.

Under the guidance of the China National Working Committee for UNESCO and the pressures from the rapid growth of Shenzhen, a charitable organization, the Hong Kong Education for Sustainable Development Association (HKESD), was established in 2003. Six middle schools and one primary school were assigned as the ESD schools in the Hong Kong ESD project [50]. Through the quality evaluation of these schools in five aspects, school management, teaching and learning, moral education activities, school campus environment, and student all-roundedness [51], the authors suggested that student learning and innovation and teacher development need to be further improved in ESD experimental schools. The report highlights that schools should encourage principals’ and teachers’ professional development in ESD and facilitate students to engage in sustainable development-related courses or programs [52].

Taiwan also generated a series of strategies to promote sustainable development. The Environmental Basic Law was granted in 2002 [53]. Putting the policy into practice, the Environmental Protection Administration (EPA) and the Ministry of Education (MOE) in Taiwan have been trying to promote environmental education (EE), which has been incorporated into the school curriculum [53]. For recent years, more than 10 EE centers have been established in Taiwan, according to the variety of geographical locations and resources. Each center is composed of university scholars who focus on environmental education, teachers from primary and middle schools, which aim to make contributions to ESD in Taiwan, and five working contents are summarized [53], (a) developing learning materials and curriculum for students of all levels, (b) organizing conference related ESD, (c) holding teacher’s workshops for ESD, (d) developing the Taiwan Greenschool Partnership Project, and (e) conducting the Taiwan Sustainable Campus Program. Such environmental education actions keep pace with the sustainable development policy framework and could help increase students’ attitudes toward environmental protection actions and skills [54,55].

### 3.4. *The Impact of COVID-19 on ESD*

In general, the pandemic had a heavy impact on schools and has caused severe damage worldwide [56]. Schools moved to teaching online or in blended learning scenarios, but many struggled with information and communication technology (ICT) infrastructure and the lack of ICT skills of teachers [57]. Exams had to be cancelled or postponed, and schools had to reevaluate how to monitor student progress and success [58]. The pandemic caused an acceleration of education inequality, especially in countries/communities where inequality was already high and access to online learning was limited [59,60]. Some indicators point to a decline in school performance [61]. The full impact of the pandemic will presumable only be seen within the coming years.

All of this also affected ESD, but in addition, there were some specific effects of the pandemic on ESD. Due to a lack of face-to-face contact activities, typical experiential ESD activities, projects such as eco days, and eco-clubs were not possible and had to be cancelled [62]. The development of sustainability competencies via online teaching is difficult. ESD requires problem or inquiry-based pedagogies. Many schools did not have any experience using such pedagogies via digital platforms. Many teachers were focused on handling other issues and lost their focus on ESD [58].

However, the pandemic seems to have had some positive effects, too. Some teachers moved from a lecturing approach to a more interactive, participatory approach to teaching and changed their role to a “facilitator” rather than “deliverer of content” [63–65]. Additionally, the use of outdoor learning spaces was encouraged. Since outdoor activities were possible, some teachers used “green” learning environments such as school gardens and woods [58]. Another study identified that sustainability enhanced pre-service teachers’ SD (students’ sustainability consciousness) in online educational settings [66].

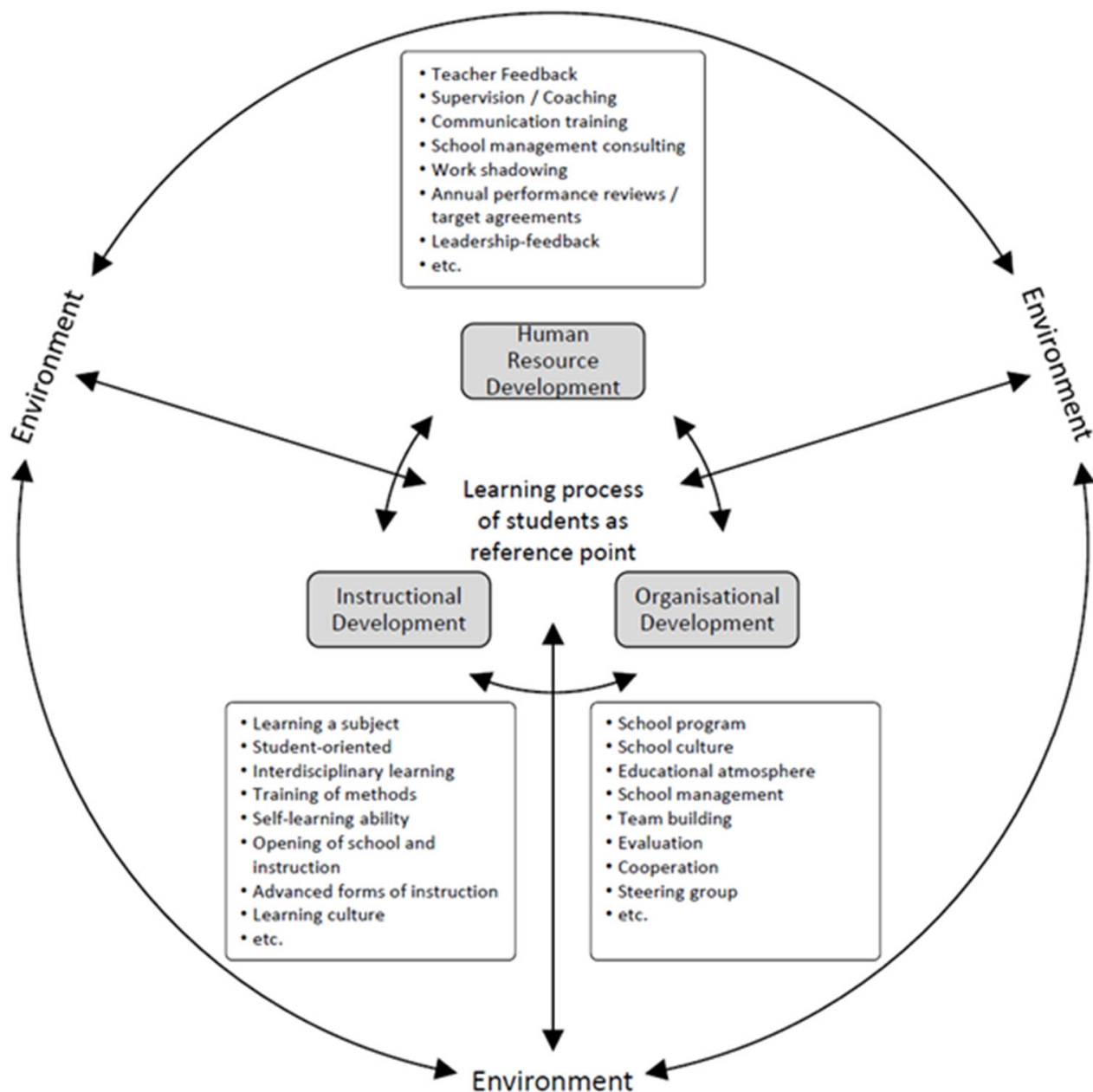
#### 4. Theoretical Background

This study refers to the whole school approach as a general background for ESD. In line with the general goal of transforming learning and training environments, this approach aims to not just teach sustainability but to integrate sustainability principles into daily practice, managing physical facilities more sustainably, and change the ethos and governance structure of the whole institution [15,44,67]. The physical place, including the building, the surrounding environment, and the resources that flow through the school, provide opportunities for education as well as a visible representation of the school’s values [68]. The approach also moves often neglected aspects, such as finances, material cycles and resource management, structural design, and equipment, into the focus [69]. The holistic transformation of a school into a learning and teaching environment that supports sustainability requires a comprehensive school development process that requires individuals across the school, school staff, faculty, students, parents, principals, and external partners to work together [23,68].

A second model we are referring to is the three-way model of school development (Figure 1) by Hans-Günter Rolff [70–72]. According to this model, school development involves three components: instructional development, human resource development, and organizational development. The application of the model requires thinking in systemic relationships. This means that all three components of school development must be considered. It is up to the school in which of the three areas they start, but in the end, “every path of school development necessarily leads to the other two” [72] (p. 19, translated by the authors). In other words, as Rolff puts it, “no lesson development without organizational development and human resource development, no organizational development without HR development, no HR development without organizational development and lesson development” [72] (p. 21, translated by the authors). These three fields of school development are interconnected and mutually dependent. To succeed in a process of school development, school management must address all three of them.

Very much in accordance with the whole school approach, the model puts all activities of school development in the context of the schools’ environment. It underscores the importance of addressing and including the various external stakeholders of the school.

Against the background of these two approaches with their holistic view of school development, the study seeks to investigate how principals in China, Germany, and the USA act to implement ESD in their schools and how they handle the consequences of the pandemic in this regard.



**Figure 1.** Three-way model of school development, Rolff, 2016, p. 20, translated by the authors.

## 5. Methods

### 5.1. Participants

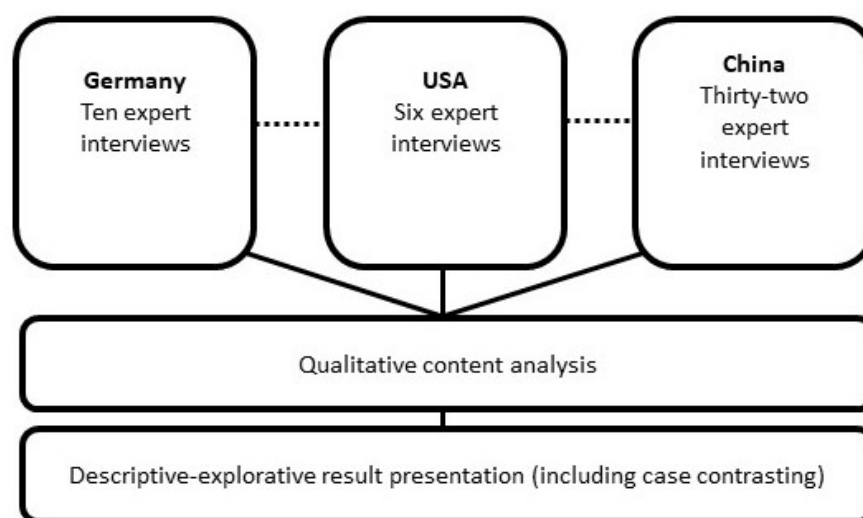
Ten German principals from schools in the state of Baden-Württemberg, six US principals from schools in the state of North Carolina, and thirty-two principals from schools in the province of Guangdong, China, participated in this study. Due to the pandemic and the resulting turbulences at schools, finding school leaders willing to participate proved difficult. Therefore, we used convenience sampling and addressed principals we had access to; study participants also recommended other colleagues. Various non-specialist school types, elementary schools, middle schools, and high schools, were represented in the group. Based on the German sample, the interviews from the USA and China were compared (Figure 2).

### 5.2. Procedures

Since this field of research is relatively new and still less developed, the study is based on a descriptive–explorative approach (Figure 2). Semi-structured expert interviews [73] with principals of various non-specialist school types were conducted in Germany, the USA, and China.

The five interview questions were:

1. In your school, do you have ESD activities/programs/curricula? If so, please describe them in detail.
2. In your school, what role does human resource management play in implementing ESD activities/programs/curricula?
3. In your school, what role does organizational development play in implementing ESD activities/programs/curricula?
4. From your perspective, what competencies must principals have in order to create/sustain ESD in their schools?
5. In what ways has the COVID-19 pandemic impacted ESD activities/programs/curricula in your school?



**Figure 2.** Qualitative design (qualitative-explorative approach).

For the purpose of uniformity in the collection of data and analysis, the German interview guide was translated and retranslated in both countries (the USA and China). Because of the semi-structured interview guide, the questions allowed open-ended responses and were flexible enough to handle the complexity of the issue. For example, the interviewer was able to collect new information on unexpected dimensions of the topics by spontaneously phrasing new or more suitable or additional questions.

In each country, the interviews were conducted by the same researcher. The interviews were audiotaped and transcribed verbatim.

For the analysis, we used qualitative content analysis, according to Mayring [74] and Kuckartz [75], as well as a deductive–inductive category system relating to the research questions (Table 1).

The involved researchers from the three countries/regions worked with the same category system, which was finally developed by comparison of the individual preliminary work in several virtual round table meetings. Furthermore, they matched and discussed selected estimates and interpretations or questions as well as the presentation of the research results analogous to the methodological, descriptive and explorative, approach. The researchers paid special attention to cross-case comparisons and selected numerous quotations to substantiate the results.

**Table 1.** Category system.

| Main Categories                      | Sub Categories                                                                                                                                                                                                                                                                                                                                                            |
|--------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. ESD activities/programs/curricula | e.g., <ul style="list-style-type: none"> <li>• school without significant/comprehensive ESD implementation (“not present”)</li> <li>• schools with an extensive ESD implementation (“present”) <ul style="list-style-type: none"> <li>- numerous (individual) activities</li> <li>- programs/curricula</li> <li>- work as part of an “ESO network”</li> </ul> </li> </ul> |
| 2. Obligation of ESD                 | e.g., <ul style="list-style-type: none"> <li>• obligatory (by district, state or federal government)</li> <li>• optional</li> </ul>                                                                                                                                                                                                                                       |
| 3. Hindering or preventing factors   | e.g., <ul style="list-style-type: none"> <li>• internal factors</li> <li>• external factors</li> </ul>                                                                                                                                                                                                                                                                    |
| 4. Role of human resource management | e.g., <ul style="list-style-type: none"> <li>• possibilities within the framework of HR development</li> <li>• limits within the framework of HR development</li> </ul>                                                                                                                                                                                                   |
| 5. Organizational development        | e.g., <ul style="list-style-type: none"> <li>• organizational anchorage <ul style="list-style-type: none"> <li>- mission statement</li> </ul> </li> <li>• level of participation (stakeholder)</li> </ul>                                                                                                                                                                 |
| 6. Principal’s competencies          | e.g., <ul style="list-style-type: none"> <li>• communication skills</li> <li>• leadership skills in different areas, understood as a “competence bundling”</li> </ul>                                                                                                                                                                                                     |
| 7. impact of COVID-19                | e.g., <ul style="list-style-type: none"> <li>• negative impact</li> <li>• positive impact</li> </ul>                                                                                                                                                                                                                                                                      |

## 6. Findings

This section presents the findings of the study. Significant quotations from participants are included.

### 6.1. Structural Anchoring of ESD (Activities/Programs/Curricula)

In this study, in the complete overview of all three countries, a wide range of ways to bring ESD to schools has been identified, a result that confirms the results of our previous studies. Principals reported single lessons, projects, or courses in school subjects, work in school farms, excursions or invitations of external experts, or even consistent curricula with ESD issues in every grade level (see Table 2). These activities also involved parents and external partners of the school: „We have carried out the, Garbage Recycling‘ project exploration course according to the age of the children and grades, allowing children, families and schools to participate and interact effectively!“ (CN\_SP5, I. 1 ff.). „The development of cooperative courses between the museum and the school allows students to gain inner experience and improve their abilities in participation“ (CN\_SP27, I. 1 ff.). The participation of the environment and the wider community of a school seems to be an important success factor: „We involved the village, of course. [ . . . ] Because our school is so small, it works only with a wide range of partners [e.g., parents, countrywomen, clubs]. Otherwise, the essential idea keeps short, I think“ (GER\_SP2, I. 103 ff.). „We were the first fairtrade-school [ . . . ]. This gave us an incredible impetus, [ . . . ], and then you get these networks, and they are quite important as external cooperation partners“ (GER\_SP3, I. 155 ff.).

**Table 2.** Selected ESD examples of realization in schools.

| ESD-Examples                                                                                                                                                              |                                                                                                                                                                           |                                                                                                                                                                                                                                      |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| China                                                                                                                                                                     | Germany                                                                                                                                                                   | USA                                                                                                                                                                                                                                  |
| “Fruit picking activities; vegetable planting activities; ecological school construction project [ . . . ]” (CN_SP1, I. 1 ff.)                                            | “Every class has to do two projects a year [ . . . ], training for the stuff is obligation, and one ESD-modul is with parents” (GER_SP2, I. 147 ff.)                      | “Saving the environment, recycling, [ . . . ]. We did World Health day where we learned about exercising but we also learned about taking care of the earth around us” (US_SP2, I. 274 ff.)                                          |
| “[ . . . ] courses [ . . . ]—topics such as resource reuse, protecting the earth, and caring for the environment are discussed” (CN_SP4, I. 1 ff.)                        | “ESD-concept [initially in primary school], From classroom to learning landscape’, competence oriented ESD and teaching” (GER_SP1, I. 157 f.)                             | “We do have a an international baccalaureate program at our school. So IB has a lot of stuff that goes with global competencies. [ . . . ] We have had like Environmental clubs and things like that [ . . . ]” (US_SP3, I. 207 ff.) |
| “School cultural management, the cultivation of students’ innovative literacy, the cultivation of students’ financial and economic literacy [ . . . ]” (CN_SP2, I. 1 ff.) | “Two activity days a year, and that’s the main thing I think—to leave the usual lessons, [ . . . ] partially planned as major events in the canteen” (GER_SP3, I. 97 ff.) | “[ . . . ] [W]e do have recycling program that we take care of with cardboard. And, we also have a [ . . . ] energy conservation policy and program where we manage electrical usage, and try to reduce that” (US_SP4, I. 228 ff.)   |
| “Cultivate young children to care for the environment, learn to classify waste and distinguish which is useful [ . . . ]” (CN_SP5, I. 1 ff.)                              | “Obvious, extracurricular partners, extracurricular places of learning play a big role in this concept” (GER_SP9, I. 439 ff.)                                             | “We are a <i>Leader in Me</i> school [ . . . ] not 100% sure if the leader in me program would fall under that ESD category [ . . . ]” (US_SP5, I. 233 ff.)                                                                          |
| “Yes, steam courses are integrated into regular classes, and zero-carbon schools are piloted” (CN_SP7, I. 1 ff.)                                                          | “Network—that plays a big role. And maybe that’s the quintessence, actual <i>be</i> a network” (GER_SP4, I. 552 ff.)                                                      | “We are a <i>Global Ready school</i> [...] And, what we have done, we’ve made a move towards teaching our staff and teaching our students about the UN Sustainable Development goals” (US_SP6, I. 208 ff.)                           |

Additionally, the results provide evidence for significant differences between the three countries, especially in terms of the type and scope of central requirements and the consequences in schools.

In the United States, where ESD is not externally mandated, ESD is often viewed as an extracurricular activity that is isolated and only sometimes embedded into other programs. Science is viewed as the one content area that is expected to support ESD. Nevertheless, some schools developed school profiles or modules which show clear links to ESD (“Global Ready school [ . . . ]—we’ve made a move towards teaching our staff and teaching our students about the UN Sustainable Development goals”, UA\_SP6, I. 208 ff.).

In China, there are no or only a few obligatory requirements regarding ESD from the district, state, or federal government. The implementation of ESD is within the responsibility of the individual school. Our study shows that this has a clear impact on the implementation of ESD, which is perceived as something additional and is not supported by official policies (“The above activities are not authorized by the government. The main reason for the implementation of sustainable development education activities in our school is based on our responsibility for education”, CN\_SP9, I. 11 ff.).

In Germany, ESD is given high priority in national and state policies (level of the Conference of Ministers of Education and Cultural Affairs); in addition (for example, in Baden-Württemberg), there are guiding perspectives (“Leitperspektiven”) anchoring ESD as part of the obligatory education plan [76]. As a result, in many schools, aspects such as the school’s mission statement, school program, a common vision, or the appearance on the school homepage are central elements to underline the importance of ESD for the school community.

Furthermore, various internal and external hindering or preventing factors were identified. Many principals described “classic” reasons, such as the lack of time, resources, or support, comparable with previous studies. In addition, principals mentioned various other obstacles that can hinder the introduction of ESD.

In the US, performance pressure is a weighty reason why ESD was not given high priority, not least because of the COVID-19 pandemic, which was also mentioned in several interviews as a hindering factor. Math and literacy are prioritized, and the principal’s job security often depends on meeting certain performance levels in students’ reading and writing. Furthermore, several principals mentioned budget problems (“One thing [ . . . ] is tight budgets [ . . . ] I think they affect the capital budget in upgrades to things [ . . . ] like solar panels or other renewable energy sources. And another restriction for the last three years I’ve worked in ‘low performing schools’, and the demands [ . . . ] on low performing schools and teachers [ . . . ] basically prioritizes the basics like reading and writing”, US\_SP4, I. 309 ff.).

A Chinese principal addressing change processes stated: “Some teachers with more years of teaching experience need some time to accept new challenges. Therefore, the school-based curriculum needs to be continuously promoted” (CN\_SP3, I. 12 ff.). Some principals mentioned obstacles from society, parents, and administrative departments: “Because of the rapid development of the gaming industry [ . . . ] in the past two decades, it is too easy to obtain material things, but less people think about sustainable development. Therefore, the society needs to reflect and pay attention to it” (CN\_SP6, I. 74 ff.).

In Germany, some principals stated that advertising for and finding teachers with appropriate competencies for ESD required a lot of time and considerable administrative expense. One principal mentioned that teachers are on load limits and that he needs flair to handle the situation.

## 6.2. Human Resource Management (HR)

The second question broached the issue of the role of human resource management in implementing ESD activities/programs/curricula, which has, of course, multifarious linkages to the follow-up question (4.3). Significant similarities between the countries were noticed as well as differences within subsamples.

In all three countries, principals pointed out that it is important to support teachers and their professional development. It is decisive to foster their motivation by recognizing their individual strengths and interests and to assign tasks accordingly: “I think knowing your staff [and] knowing what they’re passionate about in their personal lives—especially if somebody has this [sustainability] as an interest—is more likely to gain student involvement” (US\_SP1, I. 494 ff.). Training and other forms of personal development can help to develop competencies and motivation of teaching staff. Furthermore, team building is considered highly important: “I try to form teams in which the synergistic effects are also noticeable. Many teachers in high school have never experienced synergistic effects” (GER\_SP3, I. 301ff.).

In the USA and China, principals have more influence on the recruiting of personnel. Consequently, principals mention and emphasize the importance of recruitment (“Absolutely critical. Anything related to that. You want to have the right person. You want people who love science. [ . . . ] I am a recruiter when it comes to personnel”, US\_SP2, I. 321ff.; “Hire relevant new colleagues [ . . . ]”, CN\_SP7, I. 28; “Rigorous entry system”, CN\_SP30, I. 16). One Chinese principal summarized: “Human resource management is an important guarantee for realizing the sustainable development of the school” (CN\_SP21, I. 28 ff.). In Germany, leadership and “subtle intuition” in the context of human resources development were emphasized. Staff are mainly assigned to schools by the school authorities, and some principals expressed their wish to have more influence on the recruiting of their staff and criticize the current regulations that restrict principals’ possibilities to hire teachers: “As long as principals cannot select, hire and lay off their staff, they do not have all issues of school management under control” (GER\_SP6, 78. ff.).

### 6.3. Organizational Development (OD)

Implementing ESD in a school requires activities focused on developing values, culture, structures, and processes of the school as well on as the curriculum. The subsequent question of our study addressed the role of OD in implementing ESD.

Principals in all three countries pointed out that change management has high significance within this context. They also emphasized that all activities of OD are closely connected to human resource management and that one has to bear in mind that these two fields of activities are affecting each other.

US principals pointed out the significance of school improvement teams which bring innovations to the school, but that it is also important to create a supportive school culture. Both culture and organizational structure can support ESD initiatives. The performance pressure of teachers was another theme that emerged, and the main emphasis of the school programme, in their eyes, is to reach requirements in the main subjects (see 6.5).

Several Chinese principals mentioned three-year or five-year development plans for their schools. They also confirmed the great importance of HR and OD. One principal said: “Organizational development is the most important way [ . . . ], and vision, mission and culture are important means to unite people and implement the school’s development strategy” (CN\_SP17, I. 30 ff.).

In Germany, many schools developed a specific school curriculum for ESD. Networking also has an important role (see Section 5). Furthermore, the meaning of the “Whole System Approach” was emphasized. As one principal put it: “It so happened that from the very beginning of the development process, we worked with the ‘Whole System Approach’ tool as sort of a set that basically wants to look at the whole system of a school. It’s basically about four fields: It’s about the topic of teaching. It is about the topic of rooms and equipment. It’s about the topic of personnel development in the third field, and the fourth field, then the topic of external partners” (GER\_SP1, I. 184. ff.).

Within this sample, it is also evident that the current activities and programs at various schools have a “history”, which means that the current high level of the implementation of ESD is a result of development over many years (see Conclusions). For example, one school has been a CLUB OF ROME school for almost 20 years. Under the motto “think globally—act locally”, pupils learn to think out of the box, to reflect global perspectives, and to spring into action in their local environment. Another school has been a FAIRTRADE school for approximately 10 years. This campaign anchors fair trade in everyday school life and raises awareness for sustainability issues among students. For various principals, joining an ESD network was the next logical step in their work and commitment to ESD.

### 6.4. Principals’ Competencies

To create sustainable ESD in their schools, school leaders need leadership skills in different areas, understood as a “competence bundle”. Different “components”, for example, expertise in ESD, communication skills, or competency for change, were enumerated in this context.

The basis is sufficient professional and background knowledge in management, leadership, and ESD. In particular, change management skills seem to be very important for sustainable success. The principal must initiate and support processes of change for their schools as organizations. He or she must take into account the strengths and preferences of individual teachers, but he or she must also have a wider horizon and consider the whole of the school.

Some quotations illustrate even more facets. A German principal stated: “A principal needs pedagogical skills and management skills . . . ” (GER\_SP6, I. 112ff.). A US principal emphasised: “Be innovative. Trusting. Be resilient. Things will go wrong” (US\_SP2, I. 494 ff.). Additionally, a Chinese principal pointed out: “Have the spirit of continuous pursuit of knowledge. Be able to accept new things. Have the spirit of innovation and inquiry. Trust partners, be able to brainstorm ideas, and lead the team to a common goal” (CN\_SP31, I. 71 ff.).

### 6.5. Impact of COVID-19

The final question of our study touched on our main focus of interest: “In what ways has the COVID-19 pandemic impacted ESD activities/programs/curricula in your school”?

As was to be expected, a significant impact of COVID-19 could be identified in all three countries. Many of the ESD activities had to be abandoned. As a result, educational and pedagogical issues had more and more attention. Additionally, the question of how to realize online education was urgent.

In detail, some interesting findings and characteristics could be made and identified within each country. In the USA, principals reported that the COVID-19 pandemic changed the focus of the school. Principals reported that they had to prioritize supporting students’ social and emotional needs and leading the way. As a logical consequence, ESD issues became more or less meaningless.

In China, lots of outdoor activities or visits were cancelled, and the depth and breadth of school activities and courses became particularly difficult to achieve. Many principals furthermore took the view that the effects of online courses were limited. Practical teaching, courses and (especially outdoor) activities, or mass gatherings were affected (“Courses are constantly being interrupted, and resources available are reduced, especially for outings”, CN\_SP4, I. 47 ff.; “There is a certain impact, for example, intensive activities cannot be carried out, and the online teaching effect is not good”, CN\_SP26, I. 29 ff.). The combination of online and offline teaching was discussed critically, and the desired teaching effects were questioned. Individual principals referred to the psychological effects on teachers and students (“In particular, the overly formatted requirements in the process of epidemic prevention and control have obvious formalism, which has a certain negative impact on the concept of sustainable development”, CN\_SP21, I. 58 ff.). Only single opinions stated a positive impact (“Make teachers more aware of sustainable development and use this as a material for sustainable development education”, CN\_SP18, I. 39 ff.; “[...] interest in textbook learning has weakened, but the discipline of student life has improved”, CN\_SP32, I. 28 ff.).

In Germany, many similar negative effects were reported. Many principals spoke of canceled activities or the effort to map them online or in other ways. Many schools reached a standstill, for example, when the development of the school’s ESD program was abruptly halted by the pandemic (“We made the first step in 2019. Then there was more or less standstill for almost two years”, GER\_SP9, I. 38ff.). Principals also critically questioned the results of online teachings: “There is nothing like the primary experience of nature during outdoor activities”. One principal, who only recently took over his position in a new school, had the clear impression that ESD, according to the guiding perspectives in the curriculum of the state (see 6.1), was implemented only in certain subjects or even by individually engaged teachers. Conversely, he noticed the absence of a consistent school concept for ESD. In his opinion, due to COVID-19, the overall situation became even worse, and pedagogical work became significantly more important. Another principal pointedly stated that the COVID-19 pandemic “has bluntly revealed the total grievances of the school system” (GER\_SP7, I. 401ff.).

An interesting finding in the German sample is that anchoring ESD in official documents such as the education plan (see above 6.1) does not guarantee the comprehensive implementation of ESD at the individual school. Anchoring ESD in the context of networks, however, seems to increase the likelihood that the topic will not be lost sight of “after COVID” and will be taken up extensively or maybe even deepened, if possible.

On the other hand, various positive effects could be identified, too.

For example, one principal mentioned the already existing outstanding digital equipment before the pandemic was a great help for organization and facilitated online teaching during the COVID-19 pandemic (“We already had a fast internet connection. We had [...] many devices. We had fitting networks and platforms to communicate [...]” (GER\_SP4, I. 454ff.). Most of the positive effects have a correlation with the level of implementation and

memberships in networks with an explicit connection to ESD, which will be discussed later (see Section 5).

A number of principals of schools with an ESD profile stated that the pandemic even encouraged them in their intention, quasi on the basis of the motto “Now more than ever”. One principal pointed out: “There is no ‘it doesn’t work’ since the COVID-19 pandemic. [ . . . ] For our self-confidence it was a gigantic booster” (GER\_SP7, l. 401ff.). This especially applies to the work on ESD as a “basic principle”. One principal pointed out that the school wants to increase participation, a core idea of ESD.

The members of one certain network agreed to continue the work related to ESD despite the COVID-19 pandemic situation as well as possible, or rather to resume work as soon as possible. In another network, the schools have an obligation to comply periodically with quality requirements to remain in the network, and that also ensures a certain level of quality of the ESD program.

## 7. Discussion

Current discussions and policies on ESD shift the focus from teaching and learning to the institutional level and to integrating ESD into the whole system of a school (see 3.2). Against the background of the whole school approach and the three-way model of school development (see Figure 1), the results of our study indicate that a number of the participating principals are already well on the way to transforming their schools into holistic learning environments for ESD and to even develop a specific ESD profile. In their schools, they have organized various activities in a participative process of school development. In addition to addressing ESD in single lessons or isolated teaching projects, ESD is also integrated into the school’s curricula and is considered in processes such as hiring teachers or competency development. Included in many activities were not only the principal and teachers but also non-pedagogical staff, parents, and external cooperation partners. The current study also identified fundamental characteristics referring to the liability of implementing ESD in schools. In the USA and China, ESD is not externally mandated. Despite that, several schools in the subsamples made noticeable efforts related to ESD and ESD goals. In Germany, on the other hand, where ESD as a guiding perspective is part of the obligatory education plan, not all schools in the subsample made significant efforts related to ESD. That shows that official regulations do not necessarily ensure the successful implementation of ESD.

That raises the question of which success factors can affect the implementation of ESD in each school, regardless of countries or mandates. The authors assume that the role of the principals and the involvement of the school and its environment is more effective than superordinate mandates or requirements. They are unquestionably able to support involvement, but they provide no sure-fire success. In this context, the authors attribute the implementation of the whole school approach a clear greater significance (see 3.2), and in line with Rolff’s model, relationships between teaching, personnel, and organizational development become apparent. For the greatest possible success in the implementation of ESD, the complex interplay of internal and external factors at the individual school must be taken into account.

Principals, as change agents, must have the right attitude towards ESD and many competencies to put the topic into practice. They need support, just like teachers. It seems to be desirable or even necessary to take this topic into account in initial vocational and extra-occupational training as well as support for schools. The lack of resources was often criticized by the principals.

Our study revealed that several German schools were part of a network of ESD schools. Participation in networks would not solve all the challenges, but it was apparently an important success factor. The German subsample illustrates that the networks bring advantages, among other things, clear and simple additional resources for the schools, e.g., external expertise, support by external persons or „manpower“, or the possibility to exchange knowledge or talk about challenges with like-minded persons. If the goal of

implementing ESD would be reached by means of school networks, it is furthermore rather a mission for the whole of society than a „single school“ or „teachers and pupils“. In this context, as already mentioned, leadership can make a difference. Principals have a key role in transforming a school towards more sustainability and to take into account the whole background of the sustainable development goals. In order to meet the requirements, principals need many competencies in addition to profound expertise.

As was to be expected, the COVID-19 pandemic considerably hampered many ESD activities and especially processes of school development. Surprisingly, various positive effects were reported, particularly in schools that already had a highly developed ESD profile.

In the context of the COVID-19 pandemic, especially in the USA but also in China, performance pressure for teachers occurred to be one weighty factor that led to prioritizing other tasks over ESD. This raises the fundamental question, beyond the three countries we are referring to, which school system and which educational goals are fundamental in a post-pandemic phase and which methods of evolution are required in order to shape a certain future?

As far as the limitations of this study are concerned, the biggest restrictions are associated with sampling. Since obtaining access to the principals during the pandemic was difficult, convenience sampling was used by the authors. The principals in the subsamples do not represent all principals in the respective countries.

Furthermore, the data from the interviews were self-reported by the principals. Systematic triangulation of the data was not implemented within the research design. In individual cases, further information (e.g., school homepage, internet platforms) was considered to check the data situation. On the other hand, the methodology provided rich data and allowed school principals to express their points of view, which was the goal of this study. The data allowed the authors to understand school principals' perspectives on the research questions, especially with a deeper view of ESD and the impact of the COVID-19 pandemic in intended addition to the previous studies.

Finally, a survey design, in addition to this interview study, could provide a much larger sample and could increase the validity of the present results. For future research projects, it could also be important to determine which success factors are vital for implementing school networks relating directly to ESD in the context of state and district characteristics.

## 8. Conclusions

International programs and national laws are important measures, but they do not necessarily ensure that ESD is actually implemented in schools. They need to be broken down into state and district-wide strategies and activities. Even the anchoring of ESD in curricula does not suffice. Implementing ESD in schools is a multi-level project that requires the commitment and involvement of the global community, countries, states, districts, and every single school. ESD is a team task that necessitates the involvement of teachers and other staff, students, parents, and the wider community of a school.

However, ESD is also a leadership responsibility. The results of our study underscore the crucial importance of principals for the successful implementation of ESD in schools. Because of this, in the following, we suggest some possible activities to support principals.

**Principal preparation and further education:** ESD topics should be included in programs that prepare principals for their responsibilities, such as master programs or courses offered by the state. These programs should especially include issues surrounding the management and leadership of ESD: creating a vision and mission, change management, human resource management for ESD, etc.

**Principal support:** Participants of our study reported being overburdened by administrative tasks that are hindering them from focusing on ESD. School administration should reflect on how principals can be supported by reducing other responsibilities. If ESD is to

be prioritized, other tasks must be reduced. Resources are also a vital factor (teachers, time, and funding).

**Networks:** Our study revealed that being part of a network of schools that cooperate in ESD activities can be of particular help. School administrations might consider initiating and organizing more networks of this kind. Additionally, principals could possibly arrange partnerships themselves.

COVID-19 is a threat to ESD. In many schools, ESD activities totally broke down due to the pandemic. However, the study also revealed that some schools succeeded in keeping up their engagement in ESD despite COVID-19. Some were even encouraged to further pursue their involvement.

The implementation of ESD is a marathon, not a sprint.

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## Article

# Implementing Sustainability into Virtual Simulation Games in Business Higher Education

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**Abstract:** The paper aims to determine how sustainability can be implemented into virtual business simulators dedicated to higher education due to the need for raising environmental awareness among students. Climate and natural environmental changes caused by human activities require adjustments in society's mindsets and activities, especially in the business-related sector, which makes the implementation of sustainability in business higher education of crucial importance. Virtual business simulators are innovative tools in business higher education. Their use, as a part of game-based learning, is attracting increasing interest, as this method allows us to understand interactions between business decisions and their results. In this paper, we present our case study of an IT-based business simulator, which includes aspects of sustainability, and the initial experience of a group of test students participating in the business game. The paper discusses the authors' own IT solutions and the possibilities of implementing the concept of sustainability into business-oriented higher education. This paper proposed the manner of implementing sustainability, including pseudocodes, into a virtual business simulator. The results show how challenging it is to implement sustainability into game-based business education, as it increases the complexity of interactions among different aspects of running a business, including the goal of making a company more diversified.

**Keywords:** sustainability; game-based higher education; sustainable-oriented virtual strategic game; higher business education



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## 1. Introduction

Human activities, such as massive production and consumption, are often argued to be the reason for environmental challenges highlighted in the concept of sustainability [1]. Anthropogenic changes in the climate and natural environment are believed to be responsible for the majority of these challenges, and addressing them requires a change in societal mindsets and activities.

Educational centers can play a crucial role in raising awareness among future generations by providing them with useful information on sustainability and environmental protection and helping them apply this knowledge in their business decisions after graduation [2,3]. Based on the new global framework of Education for Sustainable Development that was introduced by the 40th UNESCO General Conference, universities are considered to be the main agent for achieving the UNESCO sustainable goals in three ways: by educating socially responsible citizens, by promoting collaborative work among universities and research centers, and by encouraging collaborative and multidisciplinary research activities [4].

As climate changes are directly business-related, the implementation of sustainability into business higher education seems to be crucial for making businesses more environmen-

tal aware [5,6]. Business higher education is based on two principal courses: economics and management. Both of these promote the main goals of maximizing or optimizing company profits by realizing the greatest difference between revenues and costs, while using the limited resources in the most effective manner. To some extent, the environmental concerns can also be discussed within these principal courses, as natural resources are used by businesses. However, the main aim of business higher education is not to preserve limited natural resources, but to raise profitability through the increase in demand for offered products and services and/or through the decrease in costs due to cheaper sources of raw materials and the economy of scale.

Business higher education faces its own challenges related to the methods of teaching, for example, moving from teacher-oriented methods, such as ex cathedra lectures, toward student-oriented methods, such as for example problem-based learning. One of the promising educational methods is the use of virtual simulation games during which students assume the roles of business managers and are asked to make a sequence of managerial decisions in order to understand the obstacles and consequences of running a company.

The purpose of the paper is to propose the implementation of the concept of sustainability into virtual strategic business games dedicated to business higher education. Based on the initial insights from students who tested the game, the possibility of implementing the concept of sustainability into business-oriented higher education is also discussed.

## 2. Materials and Methods

### 2.1. Sustainability

Significant evidence shows that human actions lead to much of our planet's dysfunction. The pace at which the land, the air, the climate, and biodiversity are being impacted has increased dramatically over the years. People are responsible not only for the above issues, but for the increase in carbon dioxide levels, deforestation, the elimination of natural resources, and the extinction of specific animals. Therefore, sustainability is becoming an important research area in the search for solutions to the above-mentioned human-caused concerns.

The extensive research and growing knowledge about sustainability in recent years has increased the number of definitions of sustainability [7,8]. The concept of sustainability was first applied in forestry, where it referred to the practice of never harvesting more than what the forest could regrow [9]. Among the main forestry experts who shed light on sustainability during the 17th and 18th centuries were Evelyn and Carlowirtz [8]. Next, economists also began applying the topic of sustainability: Thomas Malthus published his theory of looming mass starvation in 1798, and Harold Hotelling published his theory concerning the optimal rate of exploitation of non-renewable resources in 1931. However, the term became more recognizable after the report from the Club of Rome, which indicated that natural resources are important for the survival of the mankind, and that at the current rate of use, they will be exhausted within a couple of generations; therefore, humanity must act accordingly. Subsequently, sustainability gained more visibility due to the report from the UN World Commission on Environment and Development, also known as the Brundtland Report, where the commission introduced sustainable development as the solution to the problem of limited natural resources and the continuous aspiration for a better life. Based on the commission's definition, sustainable development is development that meets the needs of the present generation, without compromising the ability of future generations to meet their own needs [10].

There are differences between sustainability and sustainable development, even though these two concepts are often intertwined throughout history and the literature. The question that many ask is how development can be a part of sustainability. Previous studies, such as that of [11], referred to it as the necessary growth of developing countries, but the United Nations has connected development with growth, and it has also included developed countries. This having been said, many researchers argue that the meaning of development comes from Western capitalist movements that do not pay attention to

sustainability [12]. Other authors also mention that it is problematic to group development with sustainability when there have been so many ecosocial abuses throughout the history of development [13].

Sustainability is a multidimensional concept connected with the complexity of human and ecological systems, requiring the bridging of not only specialized experts, but more stakeholders on a local or global scale [14]. Sustainability as a multi-dimensional concept, is commonly separated into three main pillars: economic, social, and environmental, which represent the balance of the desirable goals between these three categories. The idea of the three dimensions of sustainability was introduced based on the triple bottom line concept developed by Elkington [15]. The idea behind this concept was to organize corporate social responsibility, such that profit, care for the environment, and the well-being of the people should all be taken under consideration. However, the pillars are addressed differently by public policies: the government is not supposed to have the goal of profit, so the profit-economic pillar is defined as the money made by the country—the GDP—thus, it can be called an economic dimension. As far as the social dimension is concerned, it refers to everything related to the well-being of humans, such as health, equity, and inclusion [16]. The environment is related to the protection of nature and sustaining and using resources with as little damage to the environment as possible. In order to achieve the sustainable goals, all of these pillars should receive equal weight. In addition, the main three pillars of sustainability can also be found in sustainable development. Economic development, as mentioned by [17], seeks to satisfy consumer demand without compromising the quality of life; social development refers to the protection of human life from pollution coming from businesses, and environmental development is about protecting the environment, for instance, by demanding that businesses keep their carbon emissions low. Even though these three pillars help us define the concept of sustainability, setting goals and strategies to help with the planning and support of changes [18], they limit the concept of sustainability to a strict structure. On the other hand, even though the three pillars may limit the concept of sustainability, there is research that considers some additional pillars, for instance, technology and innovation [19]. Sustainable pillars can be defined or assessed as conceptual foundations, and there is research justifying why and how more pillars are important to the concept of sustainability.

The environmental pillar should be as important as the other pillars for many reasons. The human population, its expected growth until 2050 [20], and urbanization is estimated to increase the pressure on natural resources, the level of air pollution, the lack of clean water and energy, and food insecurity. In addition, natural resources are also eliminated due to the constant need for development. One of the key aspects of the environmental pillar is the maintenance of natural resources, which are crucial for the survival of the human species [21]. Even though it is considered that the first steps are already being made, as the problem of natural resources has been identified, more action should be taken by different agencies in order to reach the expected outcomes [22].

Climate change is another aspect of the environmental pillar which must be considered. There is a growing consensus regarding climate change, but the general public is not always aware of natural or human causal factors [23]. Scientists generally agree that the climate change is caused, if not entirely, at least predominantly, by human activity. It has even been called anthropogenic climate changes [24–26].

## 2.2. *Virtual Simulation Business Games as Teaching Tools in Business Higher Education*

The crucial problem is how to make people in general and businesspeople in particular more aware of environmental issues in the wider context of the sustainability pillars. Business higher education seems to be the area of special importance for raising the awareness of sustainability, but the most important questions concern what should be taught (the content of courses on sustainability and the implementation of the aspects of sustainability into other business courses) and how sustainability should be taught (the most effective methods of education).

Courses on sustainability might be easier to implement into business universities' curricula, but the awareness of sustainable pillars should also be included in standard courses to make the education more coherent. Two basic courses in business higher education, microeconomics and management, teach students the main mode of business thought, which aims at the maximization or optimization of company profits by realizing the greatest difference between revenues and costs (e.g., textbooks of [27–29]). To some extent, the environmental concerns might be discussed within these basic courses, as they discuss how to utilize limited resources, including natural resources, in the most effective manner. Resource scarcity is one of the fundamental issues in business education, but the educational discussion with business students focuses on the increase in demand for offered products and services and/or the decrease in costs, thanks to cheaper sources of raw materials and the economy of scale, rather than on limited natural resources.

Business higher education must address the paradox reflecting the dilemma between productivity and sustainability. To behave in a more sustainable manner, companies should produce less and encourage consumers to consume less. However, such behavior is opposite to the major goals of businesses: to be productive, aiming at maximizing the production size regarding limited resources, and profitable, aiming to ensure that the sales revenues exceed the costs of production as much as possible. Reaching business goals often requires raising the level of production to gain scale effects. Two theories attempt to describe the impact of sustainability on the financial performance of a company: value-creating and value-destroying [30]. The value-creation approach is based on the theory that companies that adopt environmental strategies have lower performance risks, while the value-destruction approach theorizes that companies adopting sustainable strategies, such as reducing their production levels, tend to lose focus on their profitability. Past research has examined the relationship between sustainability and financial performance. Singal [31] examined the link between sustainability and economic development in the hospitality industry and found that going green does not downgrade financial performance, but pays off in future periods, as customers support green initiatives. In addition, Martínez-Ferrero and Frías-Aceituno [32] tested an unbalanced sample of 1960 multinational non-financial listed companies and come up with the finding that environmental practices have a positive effect on the financial performance of corporations. Past systematic review research examined 132 publications in regards to CSR and financial performance and found a connection between sustainability and corporate financial performance; however, the size of the firm, the type of economy, and the type of industry play an important role in this relationship [33]. When facing the productivity-sustainability dilemma, companies should consider other sustainable ways that will increase their financial performance, based on the above-mentioned literature, while maintaining the ability to lower their production levels without sacrificing profits. Moreover, deciding between sustainability or profitability, businesses should examine more factors that will allow them to find the balance between being a profitable, but environmentally friendly, company. Another dilemma of combining business and sustainability is related to positive versus normative economics as a science. Business education refers to positive economics, which analyzes and teaches how the economy operates in its all aspects. When applying sustainability, we move toward positive economics as a science that explains how the economy should operate to fulfil sustainability goals.

Another aspect of implementing the aspects of sustainability into business higher education is the problem of teaching-learning methods. This issue is part of bigger discussion related to the shift from teacher-oriented methods, such as ex cathedra lectures, toward student-oriented methods, such as for example problem-based learning; in other words, developing a more flexible teaching-learning model [34]. Problem observed today, including the lack of student motivation and engagement in learning [35,36], pushes educators to look for the most effective education methods.

The game-based teaching-learning method is a promising educational approach aimed at boosting learners' motivation, engagement, and satisfaction [35,37–39]. Game-based, or

gamification learning, adopts the educational content to the story and rules of a game [40], leading students to explore relevant aspects of games in the learning context [41,42]. The education process progresses mostly by playing games to learn the content of the education course [43].

Although the idea of implementing games into education is not totally new—it was originally rooted in the teachings of the ancient philosophers, Plato and Aristotle [44]—game-based education is still a relatively young idea in the context of higher education. The implementation of this method requires the clarification of important aspects, such as different game-based teaching and learning strategies, the variety of used technologies, digital or non-digital games, the use of particular game elements or mechanisms, etc. [45], as well as primary and secondary characteristics, such as learning support, learner control, assessment, immersion, interaction, or narrative [46]. The implementation of games into the education process can take diversified forms, starting with a relatively short game played during one class to a semester-long role play game [46].

There are different types of games used in education; among these, virtual simulation games are one of the promising methods for use in business higher education. Such games are classified as serious games, meaning digital games used for purposes other than entertainment [47], having explicit educational purposes [41]. Simulation games are an imitation of the real world, with an alternative reality and a controlled environment [41]. In virtual simulation games, students are put into the roles of business managers and are asked to make sequences of managerial decisions to understand the obstacles and consequences of running a company, as well as the interdependencies among the different areas of business [48]. Business simulation games allow students to gain personal experience related to managing a business, especially to understand relationships and market tendencies, or competitive dynamics [49].

There are several specific features of business simulation games [48]. Business simulations let learners experience different managerial roles and the areas of running a business in quasi-real situations [48,50]. Students use the trial-and-error method as they develop the ability to analyze the results of decisions, to make alternative choices, and to modify a business strategy [51]. Thanks to simulations, learners get real-time feedback on the results of their decisions, aiding them in self-assessment and supporting a better understanding of the areas in need of improvement [48]. The next feature is related to the risk of decision making, as simulations are risk-free spaces, and students can train their decision-making skills without the risk of actual failure [52].

Being aware of the discussion on the effectiveness of game-based education [35,44,53–55], we do not aim at verifying the pros and cons of such a method, but our aim is to propose the implementation of the concept of sustainability into virtual simulation business games based on the game created and implemented by the authors.

The potential to implement sustainability into business higher education through virtual simulation games is related to the following aspects. Simulations are believed to facilitate cross- and interdisciplinary learning, as students of different disciplines can collaborate to solve interdisciplinary problems [56], such as sustainability. Since games are also an education method which emotionally engages students [37], including aspects of sustainability in the business simulation should help students develop environmental awareness.

There are examples of how simulation games involving role-playing deal with climate issues, allowing learners to increase their knowledge concerning gas emission reduction and climate change actions [57], or to understand a new regulation regarding fertilizer ordinances [58]. Contrary to [59], we did not intent to implement the dilemma between biological conservation and economic development into the game; instead, our aim was to propose the algorithms for the implementation of sustainability aspects into the regular business-oriented simulation.

### 3. Results—Implementing Sustainability Aspects into Business Simulator

Implementing sustainability into virtual simulation games dedicated to business higher education is a multidisciplinary problem, as it combines sustainability, management, education, and IT software programming. In our paper, we focus on 2 issues: specific IT solutions, which we implemented into the software (Section 3.1), and initial insights from students testing our simulator (Section 3.2). By doing so, we combine the programming and educational aspects in our simulator.

#### 3.1. Assumptions and Pseudocodes

We have been using virtual business simulation games in teaching business students since 2014, in the form of the original virtual business simulator, BizArena. We use the expression “virtual simulation games” in computing as synonymous with the following three aspects of our solution:

- Our simulation is based on an IT solution based on software designed by a project team. Our simulation does not exist physically, but the software creates it;
- Our simulation is an online simulation;
- Within our simulation, we created a fictional market as close to a real market as possible, albeit a fictional one.

The first version of BizArena was developed as the part of the Strategic Management Virtual Games project, No. 2011-1-PL1-LEO05-19884, funded with support from the European Commission under the Lifelong Learning Program. This simulator was designed to manage a manufacturing company. The second version of BizArena was developed as part of the Virtual Game Method in Higher Education project, No. 2014-1-PL01-KA203-003548, funded with support from the European Commission under the ERASMUS + Program. This simulator was designed to manage a service company. The third version of BizArena was developed as part of the Central European Network for Sustainable and Innovative Economy project, No. PPI/APM/2019/1/00047/U/00001, funded with support from the Polish National Agency for Academic Exchange, and it is available at: <https://bizarena.ue.poznan.pl/cenetsie/> (access: 1 July 2022). This simulator was designed to manage a manufacturing company, in compliance with the principles of sustainable development.

In BizArena, a single game is played by several players who are grouped into teams. The purpose of the game is to establish and run a company which develops products (through R&D activities), then manufactures them and ships to retail offices operating in various local markets, where it finally tries to sell them to customers. Companies comprised of different players compete against each other for a scarce demand generated by customer groups. Each customer group has its own unique profile. Players must try to adjust the characteristics of their offer to the profiles of the customer groups. The more accurate the adjustment, the greater the possible sales. Greater sales do not necessarily mean higher profit; players must balance income with the expenses necessary to run a company, including human resource expenses (salaries, benefits, training sessions), research and development expenses, and premises expenses.

BizArena is a turn-based game—in each turn, players make managerial decisions in the following areas: marketing and sales, research and development, operations (manufacturing, inventorying, and shipment), and human resources. Turns are closed by the teacher. The teacher has access to several breakdowns presenting detailed data on the players’ decisions within all managerial areas. Before closing each turn, the teacher is able to adjust various parameters influencing game business conditions within the next turn. The comprehensive description of the BizArena simulator can be found in [60,61].

BizArena allows for the achievement of two main didactic goals. The first is to make students aware that the effects of operational activities require time to emerge; e.g., fulfilling the higher demand for products at a specific local market cannot be obtained immediately because, it is first necessary to increase production capacity by purchasing and setting up an additional manufacturing line; then, it is necessary to hire additional workers, manufacture

more products, and ship those products to local sales offices. Only then will it be possible to meet that higher demand. Therefore, managing a company requires the detailed planning of operational activities sufficiently in advance.

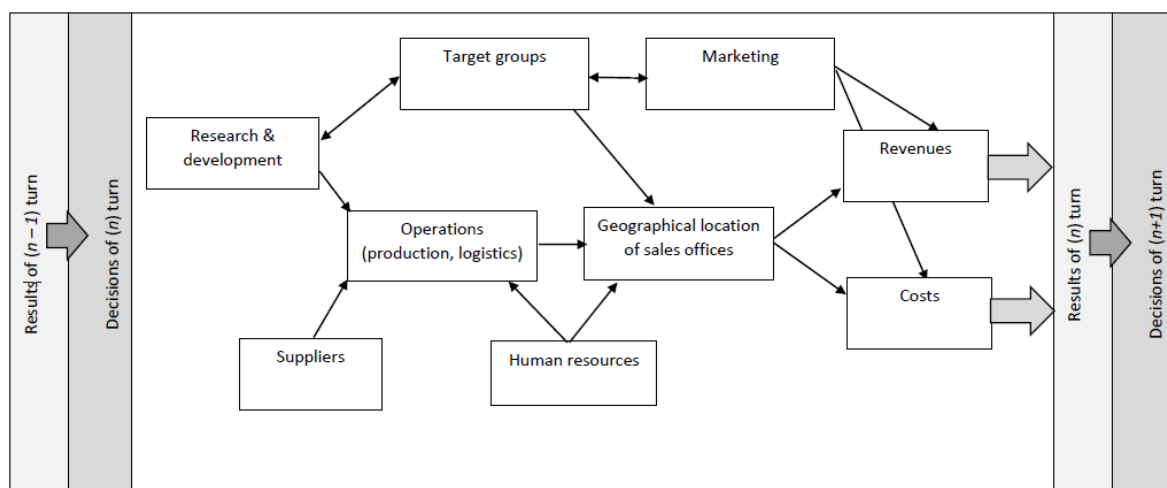
The other didactic goal of the BizArena simulator is to make students aware of the fact that managing a business requires the coordination of the decisions of various managerial areas. During university education, specific areas of business management are taught within independent courses; as a consequence, students often get the impression that these are completely independent areas, and that decisions in specific areas do not influence each other, and can therefore, be made in isolation, without requiring coordination.

The initial version of the BizArena simulator was developed based on traditional microeconomic assumptions—the company's primary goal is to maximize profit without taking into account the sustainable development principle:

- The production aspect has the form of the Cobb—Douglas function: the manufacturing cost depends on the human labor cost and the capital cost.
- Labor effectiveness depends on the number of employees, remuneration, and additional benefits and training; however, the labor supply (number of employees available to be hired) is unlimited.
- The number of components necessary to complete the final product is unlimited, and the component price is fixed.

Virtual business simulators must introduce some type of simplification in relation to the business reality due to the fact that they are used during university classes—players, being students, must be able to make managerial decisions within a limited time frame resulting from the duration of classes or the time between sequential classes.

In summary, the initial version of the BizArena simulator is a business-oriented virtual game dedicated to higher education, with the logic of managerial decisions being assumed by students-players, as presented in Figure 1.



**Figure 1.** The logic of the business-oriented version of the BizArena business simulator.

To implement the concept of sustainability into the virtual strategic game, the new version of the BizArena simulator was adopted. The initial assumptions were modified to take into account the sustainable development paradigm and thus, to educate students and make them aware of the need to favor that concept in business management. The implementation of sustainability was achieved through several aspects.

First of all, sustainability aspects are introduced in a softer and more strategic manner through a change in the scenario of the game to incorporate a discussion on sustainability into the main narration of the management classes. In the initial version, scenarios were based on environmentally neutral assumptions, but for our study, we developed a scenario using both environmentally sensitive products and target groups. Electric scooter

production is the industry represented in the sustainable-oriented version of the BizArena simulator, enabling the discussion of different issues related to the environmental aspects of transportation. To simplify the process of brand design, the sustainable-oriented version of the BizArena simulator assumes that the products are composed of three components, which refer to the materials, batteries, and the design. Two of these components are connected with some environmental aspects; the eco-friendliness and recyclability of the materials is the first component, and the durability, capacity, and recyclability of the battery is the second component. In the game scenario, some level of sustainability awareness is also implemented into the description of all the assumed target groups; however, two of the four target groups are much more oriented towards ecological sensitivity.

Second, the adoption of the game engine, being the software of the game, was also made based on the following assumptions:

- A progressive environmental tax depending on the manufacturing volume has been introduced.
- The cost of production factors is variable; in particular, the cost of materials and components is variable and depends on the demand volume.

We implemented these assumptions to solve the productivity versus sustainability dilemma. The increase in production over a certain level causes the increase in the processing of raw materials and necessitates the payment of environmental taxes. Through these two aspects, we restrict the students' decisions, to some degree. Students could reach higher productivity, but higher productivity is connected with higher expenses in our simulation game, due to the necessity of maintaining a sustainable perspective.

The environmental tax is progressive, and it is calculated on the basis of manufacturing volume; the unit of the tax amount increases in ranges within the increasing manufacturing volume. The mechanism for determining the environmental tax in the game, based on the scenario of manufacturing electric scooters, is presented in Figure 2. The tax is deducted after each turn, and it reduces the company's income for that turn. The teacher conducting the game receives full information about the amount of tax calculated for all playing teams and can change the range levels and tax rates applicable for the next turn.

#### Sustainability: Production tax

| Current turn                   |      |                          | Next turn                           |      |                                   |
|--------------------------------|------|--------------------------|-------------------------------------|------|-----------------------------------|
| Total production level [units] |      | Tax per unit product [€] | Total production level [units]      |      | Tax per unit product [€]          |
| start                          | end  |                          | start                               | end  |                                   |
| 0                              | 2999 | 0.00                     | 0                                   | 2999 | <input type="text" value="0.00"/> |
| 3000                           | 9999 | 2.00                     | <input type="text" value="3000"/>   | 9    | <input type="text" value="2.00"/> |
| 10,000                         |      | 5.00                     | <input type="text" value="10,000"/> |      | <input type="text" value="5.00"/> |

| Current turn      |                  |                    |
|-------------------|------------------|--------------------|
| Team              | Total production | Production tax [€] |
| Comet Scooters MA | 17,400           | 51,005.00          |
| FilterME          | 1800             | 0.00               |
| Wheelin' Dealers  | 0                | 0.00               |

**Figure 2.** The mechanism for determining the environmental tax in the BizArena business simulator.

The pseudocode depicting the core of the algorithm for calculating the environmental tax is presented in Figure 3.

```

function calculate_production_tax(player) {
    total_production = 0;
    for one_line in player.all_manufacturing_lines {
        total_production += one_line.production;
    }
    component_demand = total_production * COMPONENT_PRODUCT_RATIO;
    production_tax = 0;
    for i = 1 to TAX_RATES.length {
        lower_limit = TAX_RATES[i].lower_limit;
        upper_limit = TAX_RATES[i].upper_limit;
        unit_tax = TAX_RATES[i].unit_tax;
        quantity = component_demand < lower_limit ?
            0 : min(component_demand, upper_limit) - lower_limit;
        production_tax += quantity * unit_tax;
    }
    return production_tax;
}

```

**Figure 3.** The pseudocode of the algorithm for calculating the environmental tax in the BizArena business simulator.

The prices of the components and materials needed to manufacture the final product are variable and depend on the current demand generated by players in a given turn. The component pricing mechanism in the game based on the scenario of manufacturing electric scooters is presented in Figure 4.

#### Sustainability: Component demand

| Team              | Production line       |       |     |     | Product                |     |     |              | Production Quantity | Total component demand |         |         |
|-------------------|-----------------------|-------|-----|-----|------------------------|-----|-----|--------------|---------------------|------------------------|---------|---------|
|                   | Name                  | Size  | MAT | BAT | Name                   | MAT | BAT | DES          |                     | MAT                    | BAT     | DES     |
| Comet Scooters MA | Line Eco Scooters 1   | large | 9   | 9   | Comet Eco Scooters     | 8   | 8   | 4            | 5000                | 40,000                 | 40,000  | 20,000  |
|                   | Line Fashion Scooters | large | 7   | 7   | Comet Fashion Scooters | 6   | 6   | 9            | 9500                | 57,000                 | 57,000  | 85,500  |
|                   | Line Value Scooters   | large | 4   | 6   | Comet S-Value Scooters | 2   | 4   | 2            | 2900                | 5800                   | 11,600  | 5800    |
| FilterME          | Line 2                | small | 9   | 9   | SolarX                 | 8   | 8   | 6            | 1800                | 14,400                 | 14,400  | 10,800  |
| Wheelin' Dealers  | Production Line 1     | small | 8   | 8   |                        |     |     |              |                     |                        |         |         |
|                   |                       |       |     |     |                        |     |     |              |                     |                        |         |         |
|                   |                       |       |     |     |                        |     |     | grand total: | 19,200              | 117,200                | 123,000 | 122,100 |

| Supplier              | MAT prices [€] |       |              |           | BAT prices [€] |      |              |           | DES prices [€] |      |              |           |
|-----------------------|----------------|-------|--------------|-----------|----------------|------|--------------|-----------|----------------|------|--------------|-----------|
|                       | init           | max   | current turn | next turn | init           | max  | current turn | next turn | init           | max  | current turn | next turn |
| China Motor Parts Inc | 2.00           | 10.00 | 5.68         | 5.68      | 4.00           | 8.00 | 8.00         | 8.00      | 5.00           | 7.00 | 7.00         | 7.00      |
| Jumac Industries      | 3.50           | 10.00 | 9.94         | 9.94      | 3.50           | 8.00 | 8.00         | 8.00      | 4.00           | 6.00 | 6.00         | 6.00      |
| PaxWater              | 3.00           | 12.00 | 8.52         | 8.52      | 3.50           | 8.00 | 8.00         | 8.00      | 4.50           | 5.00 | 5.00         | 5.00      |

Refresh data

**Figure 4.** The component pricing mechanism for the BizArena business simulator.

In this scenario, three components are required to manufacture electric scooters: MAT (materials), BAT (batteries), and DES (design). The components are provided by three suppliers, where each supplier has a different price for each component. The range of price changes is specified by the initial and max values. The final price for the next turn is determined on the basis of the grand total demand generated by all players in the current turn. The component pricing protocol is presented in Figure 5.

```

if total demand for manufacturing components exceeds MAX_DEMAND units
then
    for every increase of demand by DEMAND_INC [%]
    the next turn component's price will be increase by PRICE_INC [%]

```

**Figure 5.** The component pricing protocol for the BizArena business simulator.

The implementation of this protocol in the game based on the scenario of manufacturing electric scooters is presented in Figure 6.

| Demand adjustment protocol                           |                                           |
|------------------------------------------------------|-------------------------------------------|
| If total demand for manufacturing components exceeds | <input type="text" value="10,000"/> units |
| then                                                 |                                           |
| for every increase of demand by                      | <input type="text" value="10"/> %         |
| the next turn component's prices will increase by    | <input type="text" value="20"/> %         |
| <button>Recalculate</button>                         |                                           |

**Figure 6.** The component pricing protocol in the game based on the scenario of manufacturing electric scooters.

The pseudocode depicting the core of the algorithm implementing the component pricing protocol is presented in Figure 7.

```

function calculate_component_price(component_total_demand) {
    demand_inc_factor =
        (component_total_demand / MAX_DEMAND - 1) / DEMAND_INC;
    price_inc_factor = demand_inc_factor * PRICE_INC;

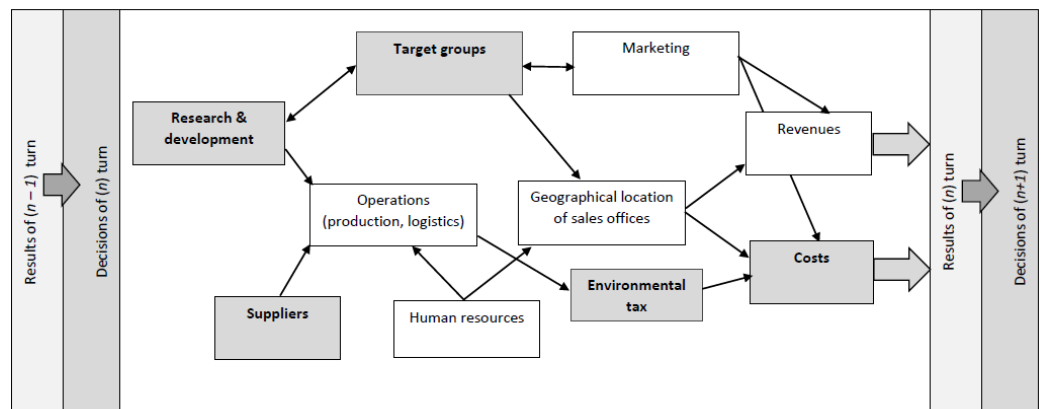
    next_round_price = round((1 + price_inc_factor) * INIT_PRICE, 2);
    if (next_round_price > MAX_PRICE) {
        next_round_price = MAX_PRICE;
    }

    return next_round_price;
}

```

**Figure 7.** The pseudocode of the algorithm implementing the component pricing protocol in the BizArena business simulator.

In summary, the implemented aspects of the sustainability-oriented version of BizArena simulator are highlighted (in grey and bold) in Figure 8.



**Figure 8.** The logic of the sustainability-oriented version of the BizArena business simulator (sustainable aspects highlighted in grey and bold).

### 3.2. First Insights of the Testing Students

During the spring semester of the academic year 2020/2021, between March and June 2021, a group of students at the Poznan University of Economics and Business, Poland, participated in the management course of based on the sustainability-oriented version of BizArena simulator. They were international students, studying in the third (last) year of bachelor's study in the international business program. The testing group consists of 18 students, including 10 men and 8 women. The students were divided into 5 teams, with 2–4 people in each group; however, the students chose their own teams, based on their preferences and previous experience.

Within the course, as the students proceeded through the simulation game, they were expected to establish and run a virtual company, competing with each other during 10 decision turns. Their initial situations were the same; but with the progress of the game, the situation of each team changed, depending on both the quality of their own decisions and the quality of their competitors' decisions. The general workflow of the students was as follows: after the presentation of the game logic and the scenario description, students determined their business strategy, mostly aimed at the target customer groups and the development plan; then, the students made a set of managerial decisions for each of 10 decision turns; finally, they were expected to make the final presentation of their strategy and its subsequent results. The students also met with a teacher weekly to explain their doubts and to discuss their current progress. The final grades of the students for this course depended partly on their weekly activities, but also on the results of the game for the aspects of revenue, market share, and financial cashflow.

The insights regarding the possibility of implementing aspects of sustainability into business higher education through the use of strategic games come from both qualitative (discussions with the students) and quantitative (game results) sources.

Discussions with the students, both through the whole semester and at the final presentation at the end of the course, revealed that all the students referred to sustainability when they presented their business strategy. The students determined to focus on the most environmentally oriented target groups, to create environmentally friendly product brands, and to restrict the development of their virtual companies with the respect of limited resources. However, when comparing these declarations with the decisions made by the students, some doubts arise. Looking at virtual brands designed by the students, there were two components that referred to environmental and sustainable aspects: materials and batteries. While designing their brands, the students were supposed to assign a value from 1 to 10 to these components, meaning that the higher value is related to the higher level of eco-friendliness; however, the costs of production are also higher. In total, the students created 21 brands, where the average value of the materials' component was 5.6 and that of the battery component was 6.5. Out of 21 brands, in the case of 12 brands, the value of the materials component was higher than 5, and in the case of 13 brands, the value of the battery component was higher than 5. This means that at the declaration level of strategy, the students were very open to considering sustainability. However, when it came down to real decisions, they combined these strategic declarations with the costs of production and attempted to find a compromise. Sustainability was seen in the students' declarations, rather than in their manner of making decisions.

Looking at the environmental tax and the mechanism of the increase in component prices, only one out of five teams of students realized that sustainable aspects impacted their financial situation and tried to adjust their decisions. The problems regarding component prices and taxes were discussed with this team during weekly meetings. Other students did not discuss these aspects, although they might not have been aware of them, as their scale of virtual production was much lower and less impacted by taxes and increases in components prices. However, looking at the same aspects from the point of view of the game results, in the cases of three out of five teams of students, the prices of components increased twice, on average, because of the increase in the demand for the components.

Two out of five teams paid environmental taxes, but their level was rather low, compared to the revenues, and therefore, might not have been deeply analyzed.

Some of student teams struggled to understand all the interactions among business decisions in the game, and for this reason, sustainability aspects could only be presented to them indirectly, using the scenario with a specific product, components, and target groups of virtual customers.

#### 4. Discussion

The anthropogenic character of changes in the climate and the natural environmental requires a shift in the way society thinks and acts, especially in the business context, requiring the implementation of sustainability into business higher education [5,6]. The challenge of this implementation comes from the fact that business education focuses on profitability, emphasizing the importance of the economy of scale, while sustainability is related to responsible production and consumption, often translating into the reduction in both. The educational challenge is related to the dilemma between productivity and sustainability, highlighted by the value-creating and value-destroying theories [30]. In the paper, we aimed to discuss these issues from the perspective of a virtual business game, dedicated to business students, simulating the running of a company. The use of game-based learning, especially business simulators, is a promising educational method; by pushing students to make a set of managerial decisions and allowing them see their results, this method allows students to understand the complexity of these interactions.

We proposed pseudocodes reflecting aspects of sustainability to be implemented into the game engine; namely, that sustainability is related to environmental taxes, depending on the volume of production and the mechanism of an increase in the prices of raw materials, depending on the demand growth. Our conceptual model can be used as a guideline for the developers of educational games, suggesting ways to design and implement such a simulator. We also introduced sustainability into the game scenario, mostly in the description of product lines and target groups. We tested these solutions with the initial group of test students who participated in the simulation.

After analyzing and observing the students' behavior while engaged in the virtual game, we came up with the following conclusions. First of all, we found it a challenging task to find the best way of integrating the business logic and sustainability logic together in one virtual game. Both logics consist of many different aspects that are not easy to combine in a single virtual game. By implementing sustainable logic into business logic, we made the simulation far more complex, which, on the one hand, reflects a real-life dilemma, but, on the other hand, makes it more difficult for students to understand.

The challenges faced by the students in integrating business and sustainability logic into the decisions made during the business simulation game confirm the multi-dimensional and complex nature of sustainability [14]. Our observations are also in line with the belief that simulations facilitate the cross- and interdisciplinary learning of students [56].

Our observations also confirm the benefits of some features of business simulation games, such as experiencing managerial roles in quasi-real situations [48,50], making and modifying a business strategy using a trial-and-error method [51,52], and receiving real-time feedback on the results [48].

Second, the students' difficulties with understanding the virtual game could be explained by the fact that most of their previous courses had been focused on the separate aspects of management and business, for instance, economics, marketing, and management. In the case of the virtual game, several business aspects were implemented together, so students experienced difficulties applying their theoretical knowledge in making business decisions. As sustainability is a broader concept, it is difficult to add it to the virtual game by adopting some aspects of sustainability in business decisions. Thus, the main challenge that we noticed is the integration of all aspects of business and sustainability in one virtual game. In order to do so, it would not only require additional programming work, but also

a high level of understanding of both concepts among students in order for them to be able to apply their knowledge in their business decisions in the virtual game.

One possible solution would be to combine the virtual game with discussions or case studies on sustainability-related business aspects, which could provide students with a better background in the field, and then allow them to use this knowledge in a practical way through the virtual game.

We also face some limitations in our paper. As we aimed to combine the discussion on programming and the educational aspects of our simulator, we limited the students' outcomes regarding their first insights. Further research requires deeper qualitative and quantitative analyses of students' outcomes in understanding the aspects of sustainability in businesses with the use of simulators. Special attention should be given to the comparison of understanding sustainable aspects of management with the use of a business simulation game and other educational approaches. Another drawback of our research is related to the fact that it was restricted to a one-university perspective. To overcome this limitation, further research should include the feedback and outcomes of students from different universities.

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## Article

# Attributes and Knowledge of the Lead Organizer in Planning a Virtual Teacher Professional Development Series: The Case of the Organizer of the Schoolyard Network

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**Abstract:** Teacher professional development opportunities are woven into the structures of license renewal and school expectations, but the opportunity to profoundly develop in a professional and broad manner is still often a struggle for educators because of financial and time-oriented constraints. The Schoolyard Network is a professional development series of virtual meetings conducted by the Great Smoky Mountains Institute at Tremont to support participating educators in exploring outdoor learning opportunities with K–12 students. This key case study describes the Schoolyard Network’s lead organizer’s knowledge and perspective of running this exemplary case of a virtual outdoor experience platform. Findings suggest that the utilization of an outdoor, experiential, inquiry-based design, while prioritizing mindfulness and conversational techniques such as active listening, reflection, and relationship building are effective design principles for virtual teacher professional development, albeit through a complex, unique system. A model of impact suggests that the Schoolyard Network structure provides meaningful STEM experiential learning activities for educators impacting classrooms across a broad range of environments and geographic proximity.



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**Keywords:** sustainability education; STEM education; outdoor education; sustainable teacher professional development; virtual teacher professional development; inquiry-based professional development; teacher leadership

## 1. Introduction

The emergence of Science, Mathematics, Engineering, and Technology (STEM) as an integrated, cohesive knowledgebase is changing how schools and communities prepare students for society. The direction of a student’s attitude toward future STEM careers can be altered when STEM is coupled with real-world applications (Binns et al., 2016), especially when applications extend outside of school buildings into communities, work environments, or broadly speaking, to the outside world (CoSTEM, 2018). Given teacher shortages and the complexity of recruiting, retaining, and growing strong cohorts of teachers (U.S. Department of Education, 2024), STEM professional development leaders who design and implement professional development are a critical bridge to supporting and retaining practicing teachers (Bintz et al., 2017) and can provide support structures to stabilize school staffing issues.

The Great Smoky Mountains Institute at Tremont (GSMIT) is an established STEM and outdoor education organization that, for the past 54 years, has served educators and students (GSMIT, 2023c). GSMIT extends teacher professional development supports

beyond STEM and outdoor content by encouraging educators to coteach customizable programs, with cross-cutting themes woven into STEM lessons including political science, social-emotional learning, and sustainability topics. In order to lessen the impact of financial and travel challenges for schools, and to stay connected to educators during the COVID-19 pandemic, GSMIT created the Schoolyard Network as a virtual space for educators to collaborate and discuss pedagogical strategies for schoolyards (GSMIT, 2023b). The Schoolyard Network is a professional learning community (PLC) or an organizational structure that researchers found to help improve student learning through teacher training (M. Lee et al., 2022; Stoll et al., 2006). The Schoolyard Network (SYN) provides teachers with a PLC that prioritizes teacher autonomy (DuFour, 2004) through regular monthly meetings on Thursdays from 4:30 to 6:00 p.m. supporting the call to provide educators explicit support to plan and implement outdoor lessons at their schools (Davies & Hamilton, 2018). With support, educators can avoid common misunderstandings that school outdoor spaces are not laboratories for learning (Correia et al., 2024; Huggins, 2012), and remove barriers to help students learn in outdoor environments (Edwards-Jones et al., 2016; Feille, 2017; van Dijk-Wesselius et al., 2020). There is evidence in PLC research showing that leadership is often a key stakeholder to the PLC's success as a driving force in pedagogical transformation (de Jong et al., 2023; Stoll, 2020). Led by an experienced, expert lead organizer from GMIT, the Schoolyard Network educators work together through a series of professional development sessions during the academic year to discuss and implement highly effective pedagogical methods utilizing outdoor learning in their individual, unique local schoolyards.

Connecting educators to biodiverse learning environments during professional development is an actionable intervention to improving sustainability education for K-12 students but is often unachievable because of financial and time constraints. By providing educators access to a place-based PLC focused on teaching outdoors, educators can replicate these powerful inquiry-based experiences with their K-12 students. Designing meaningful professional development sessions is complex because professional development needs to connect with an educator's identity, operate within school constraints, and be culturally responsive (Carrier et al., 2014; Darling-Hammond et al., 2017b) along with avoiding pitfalls that can feel unavoidable such as a dysfunctional school culture or lack of shared vision (Erawan & Erawan, 2024). Given the complexity of designing meaningful professional development, our research team investigated the lead organizer of the Schoolyard Network, given its exemplary online, organizational structure and extended community impact.

The aim of this key case study is to provide a model describing the structure supporting the Schoolyard Network and answer the following research questions:

- (1) What is the organizational structure that supports the lead organizer of the Schoolyard Network to make pedagogical choices for this PLC?
- (2) What experiences does the lead organizer have that drive the Schoolyard Network?

The findings of this research aim to provide further support on how to combat calls to improve the outcomes of STEM higher education (Davies & Hamilton, 2018; Gamage et al., 2022; Taylor, 2012). Given educators are wanting and willing to progress past replicating indoor-instruction outside a school building (Maynard & Waters, 2007), meaningful, timely, relationship-driven professional development like that provided by the Schoolyard Network might be the missing support for educators. The remainder of this article is as follows: Section 2 provides organization background about GMIT and experiential outdoor learning. Section 3 describes the materials and methods utilized grounding this key case study. Section 4 describes the results and offers a model describing the leadership structure of the Schoolyard Network PLC. Section 5 presents a discussion with key attributes PLC organizers should consider in the design process.

## 2. Organizational Background and Theory

Delivering meaningful outdoor, inquiry-based lessons requires knowledge involving both content and pedagogy. We know educators often begin the transition to using outdoor lessons with content knowledge limitations (Jenkins et al., 2015) suggesting we should support educators with meaningful, systematic professional development before sending them off to try pedagogical tactics on their own (Darling-Hammond et al., 2017b; Erawan & Erawan, 2024). There is evidence that consistent, outdoor experiential learning professional development can lessen the chance for negative outcomes for K-12 students during outdoor experiential learning opportunities (Carrier et al., 2014; S. Lee, 2019) and the key to understanding most successful professional development opportunities often lies in understanding the human leadership team-making decisions about *what* information is delivered in the professional development and *how* that material is delivered. In other words, a single person with the right knowledge and experience skillset can often effectively design and implement meaningful professional development for educators. Therefore, conducting a case study focused on the key leader of the Schoolyard Network provided the mechanism for understanding the organization's effectiveness.

A case study allows researchers to study the complete picture along with analytic insights through an in-depth investigative process on a topic of research (Thomas, 2021). This case study focuses on the experience, characteristics, and decisions the director of GSMIT's Schoolyard Network demonstrates to organize the professional development sequence. Researching key personnel who hold deep pedagogical knowledge as to how to evaluate and implement outdoor lessons is meaningful to consider how similar PLCs could emerge in other organizations with other teacher populations. Since 1969, GSMIT has continued to evolve their clear mission of impacting youth, educators, and adults through a variety of programs that promote self-discovery, critical thinking, effective teaching, and leadership (GSMIT, 2023c). The experiential learning activities available at GSMIT are woven with academic rigor, providing the necessary support for educators to compose their own lessons in their own schoolyards even though schoolyards are limited, or provide challenges in cultivating relationships with nature. The challenge extends beyond the limitations of outdoor wildlife to lessons-design limitations in clear connections with indoor curriculum and limited administrative support resulting in unrealized opportunities (Dyment & Reid, 2005).

As the calls for revolutionizing sustainability education continue to increase (OECD, 2021), global challenges continue to emerge for classroom educators to design, develop, and implement meaningful experiences situated in context for their students. But we know student growth while experiencing outdoor learning opportunities reaches beyond just learning content, and into physical, social, and mindful developmental milestones (Johnson, 2007). Often these developmental milestones are less celebrated or translate poorly to high-stakes assessment scores. However, developmental milestones significantly impact K-12 students and their teachers who love and long to see student growth and development.

### 2.1. Background on the Great Smoky Mountain Institute at Tremont

A solid organizational support system committed to educators, students, and the local and extended community is essential to building long-term relationships with educators. GSMIT is a non-profit organization that collaborates with the Great Smoky Mountain National Park organization to help deliver critical programming opportunities through residential programming, research, community engagement, and advocacy for outdoor learning initiatives (GSMIT, 2023a). The individuals that are attracted to GSMIT can participate in programming for adults and families, summer youth, and teacher professional development opportunities on campus. All these programming opportunities focus on the

goal of connecting individuals to outdoor learning in a unique, hands-on manner. Intricate, carefully planned programming emerges across a variety of groups visiting GSMIT's campus including opportunities to learn photography, become naturalist certified through the Southern Appalachian Naturalist Certification Program, themed youth programming such as the Girls in Science camp, and wilderness backpacking opportunities (GSMIT, 2023b).

One of GSMIT's major organizational efforts is to improve connections with school districts and educators because they are key stakeholders in promoting, connecting, and sending visitors to GSMIT's campus. To streamline the connection with educators, GSMIT has established housing and meal structures on its campus, eliminating or lessening many logistical challenges that educators struggle with during field trips or experiential learning opportunities. The place-based programming provides opportunities for educators to learn how to teach outdoors while lessening logistical burdens by using campus resources.

## *2.2. Background on GSMIT's Educator Programming*

GSMIT provides a variety of outreaches targeting educators across K-12 grade bands and subject areas. For example, GSMIT offers Teacher Escape Weekends where educators come to campus for a weekend and engage in experiential learning opportunities and prepare educators for their class trips with students during the coming year. This outreach aims to support cooperative teaching between Tremont faculty and practicing K-12 educators to deliver hands-on lessons and develop confidence through coteaching activities. Perhaps most importantly, Teacher Escape Weekends provide a mechanism to entice educators to the GSMIT campus with other like-minded educators and cultivate relationships to support pedagogical development.

GSMIT provides other programming options aimed to connect to educators including Schoolyard Network programming, Schoolyard Escape, and Schoolyard Walks. The Schoolyard Network is a series of monthly, virtual professional development sessions conducted at convenient after-school times for educators to enact inquiry-style, outdoor experiential learning lessons. The Schoolyard Escape is a single-day workshop hosted at a centralized school that provides educators who attend the Schoolyard Network sessions the chance to apply lessons learned, catering to a variety of educator experience levels with outdoor pedagogy through carefully designed programming and grouping. Schoolyard Walks are a new programming effort that include GSMIT faculty visits to schools with the purpose of helping to design and provide outdoor lesson support structures for educators. The variety of teacher professional development opportunities provide options for K-12 educators to choose how to connect professionally with GSMIT in a manner that fits their circumstances.

The Schoolyard Network and the Schoolyard Escape are both exceptionally rare examples of PLC outdoor experiential professional development programming that is being conducted by non-profit organizations connected to the National Park System. The regular schedule, consistent leadership and participants in the PLC provide a unique case study opportunity. Teacher attendance of Schoolyard Network monthly sessions has grown substantially since its inception in 2020, with attendance numbers during the first two academic years averaging around six regular attendees committed to the PLC. During the 2022–2023 academic year, the PLC grew to 15 regular attendees with usually around five newer or perspective participants across sessions, while during the most recent academic years there are 20 regular attendees and five newer or perspective participants. The group is supported in-between monthly session meetings with reminders and additional posts of information to maintain a connection between group members. Similarly, the Schoolyard Escape continues to be a culminating, in-person connection Schoolyard Network PLC members attend, with registration maxing-out at 30 participants each of the last three years.

### 3. Materials and Methods

The design of this case study was crafted to articulate the lead organizer's pedagogical choices for the Schoolyard Network because of its exemplary reputation for providing virtual experiential learning professional development for educators across the Midwest and Southeast. GSMIT was selected because it is one of only two non-profit organizations in the United States (i.e., Teton Science School) that runs a regularly meeting PLC operating closely with the National Parks Service. The Schoolyard Network organizer is a key case study or is a near-perfect example of an organizer who runs a very successful, ideal, outdoor virtual learning professional development series, allowing for direct insights into a topic (Thomas, 2021). The perspective, knowledge, and pedagogical choices of the lead organizer provide a descriptive example of how educators engage with the Schoolyard Network. Illustrative, descriptive, and authentic artifacts connecting the leadership structure, professional development sessions, and experiential learning were gathered, analyzed, and refined. Because the goals of the Schoolyard Network are to connect a community of educators with each other to highlight successes, ask questions, share resources, and build camaraderie through specially designed professional development sessions (GSMIT, 2023b), the lead organizer's professional experiences and pedagogical decisions for sessions are the funneling mechanisms for teacher professional developmental outcomes.

This case study aimed to understand the Schoolyard Network's lead organizer and their pedagogical choices in planning the Schoolyard Network. The research was conducted through in-depth interviews following completed Schoolyard Network sessions to learn about the enacted professional development techniques. Semi-structured interview protocols were used to guide conversations and understand how the lead organizer successfully planned SYN session experiences and provided guidelines for researching the complex knowledge involved in planning professional development opportunities. Using written transcriptions, emerging themes were confirmed across research team members. Semi-structured interviews aimed to understand and articulate different constructs that are woven into Schoolyard Network sessions including the role of STEM content knowledge in professional development design, the role of pedagogical knowledge in professional development design, the support structure of professional development activities to utilize productive struggle and the lead organizer's beliefs and efficacy about the program and outdoor learning. The research design utilized multiple Schoolyard Network sessions to weave together the key characteristics and attributes of the lead organizer, providing a lens into their professional development choices. Overarchingly, data sources were woven together to describe what key attributes existed in the lead organizer to successfully and consistently implement this professional development program.

A macro-view of the research design consisted of a series of four semi-structured interviews completed over the course of four months after members of the research team observed four unique, Schoolyard Network sessions. The Schoolyard Network annual design is structured to run professional development for eight sessions, so studying half the series seemed reasonable to understand the pedagogy and organization without overburdening the lead organizer and research team. This interview structure also provided an opportunity to preliminarily analyze session transcripts and improve and develop subsequent interview protocols for the following Schoolyard Network session.

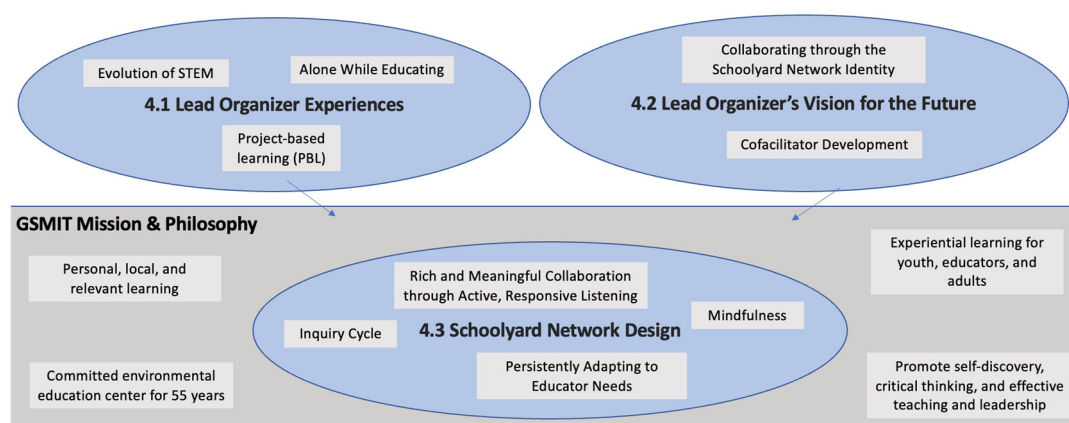
Interview protocols were designed to increase the depth of conversation and understanding of the construct at hand (i.e., the lead organizer). Pre-coding through the form of preliminary jottings was utilized with both the goal of understanding the construct (Saldaña, 2013), but also improving question quality in subsequent interview protocols. For example, questions that lacked specific responses in the first interview were sometimes followed up in a second interview question by asking the lead organizer for a specific

example from their life concerning the topic at hand. This responsive process allowed for not only improved question development but also allowed for the coding process to be a cyclical act of analysis (Basit, 2003) that allowed for the meaning-making process to begin early.

Transcripts were electronically transcribed and then manually blinded, followed by unit breaks (Gale et al., 2004) to arrange text into bundles of the lead organizer's commentary, to highlight topic or subtopic shifts and prepare transcripts for descriptive coding (Miles & Huberman, 1994; Saldaña, 2013). Themes were then developed separately across the coding team with an emphasis on meaning making (Thomas, 2021), linking word choice across researchers to the qualitative data presented utilizing tabular markings and cross-interview connections. Developing themes from the data were considered an appropriate process given this qualitative study explored an individual's psychological world, constructs, and identity development (Smith et al., 2008). Themes were refined together through conversations and debates to categorize and then form an analytic synthesis of overarching themes (Rubin & Bellamy, 2012). These overarching themes were the backbone in conversations to develop a system theory of the lead organizers guiding experiences, vision, and consequently the Schoolyard Network's professional development design. Disagreements by researchers were resolved by using further analysis of data and multiple meetings to discuss codes, themes, and overarching themes. Finally, to improve the trustworthiness of the results, the research team utilized member checking techniques, or sharing findings with participants to validate the findings (Espedal et al., 2022). The researchers used member checking by offering the lead organizer an opportunity to approve their narrative contributions of the study in the research report in rough draft and final draft forms (Carlson, 2014; Creswell, 1998).

#### 4. Results

Successful professional development experiences for educators are carefully planned and intricately layered (Darling-Hammond et al., 2017a; Fairman et al., 2020). We know that teacher capacity to manage their professional life phase is complex and dependent on resilience (Gu & Day, 2007). With the primary goal of this article being to articulate the SYN lead organizer's skills, attributes, and design choices in developing this series of professional development opportunities, the following model in Figure 1 provides an outline of their perspective. Past (i.e., Lead Organizer Experiences), future (i.e., Lead Organizer's Vision for the Future), and the resulting professional development design attributes embedded in the context of GSMIT's Mission and Philosophy are discussed in detail with codes to support the model.



**Figure 1.** Schoolyard Network visual of lead organizer.

An important distinguishing attribute of the model in Figure 1 is how the lead organizer's experiences and vision interact with the GSMIT's mission and philosophy (GSMIT, 2023a) which functions as the underlining support for the Schoolyard Network. GSMIT is historically well known for its ability to deliver impactful, in-person experiences for K–12 educators and students, but the COVID-19 pandemic and transitions to remote instruction repositioned how K–12 teachers were connecting with the organization. Therefore, the design of SYN sessions has deeply grounded philosophical underpinnings that influence the decisions of the lead organizer. The following result sections are organized to describe emergent themes of the lead organizer's influences within the organization context. A series of quotes from interviews are provided as examples of statements that led to overarching themes.

#### 4.1. Lead Organizer Experiences

The lead organizer's background was uniquely positioned for a role in organizing and cultivating a deep community in the Schoolyard Network. Professional experiences led to three major developmental themes influencing the Schoolyard Network's core: alone while educating, the evolution of STEM, and project-based learning (PBL).

##### 4.1.1. Alone While Education

At the beginning of their career, the lead organizer felt isolated. There were a variety of factors that led to the deep-rooted feeling of loneliness; they were the only English as a Second Language (ESL) teacher in their school building, they had classes of students across grade levels, and there was no PLC or meaningful educator community for support. The lead organizer's experiences with loneliness influence how they reach out to educators in the Schoolyard Network. There are intentional pedagogical design choices and actions during Schoolyard Network sessions to reach educators across the virtual platform. Personal experiences of loneliness were a driver for an intense interest in connecting practicing educators to in-person activities, including the development of the Schoolyard Escape and trips to Tremont. An interview response near the beginning of the interview series highlights the lead organizer's loneliness struggle:

*"And I felt alone constantly. I felt on an island. I was the only ESL teacher in our building and just so like I had to figure it out myself in every definition of that of that word. It was hard. So you know, I kind of came into teaching feeling like it's a like figure it-out-for-yourself job and I did. But it wasn't that sense of community that I think in undergrad we were all hoping we're for like, oh, we're all going, like, plan together and think about how kids can work together and like there's all these visions of what could be and that unfortunately, at the beginning of my career was not the reality I was faced."*

Because of the lead organizer's loneliness experiences, Schoolyard Network sessions clearly attempted to understand how educators are feeling after the school day, even with the challenge of connecting virtually through technology.

##### 4.1.2. Project-Based Learning

After transitioning from a more traditional teaching role with Teach for America, our lead organizer transitioned into an instructional coaching role seeking to support educators through similar types of challenges. From the lead organizer's perspective, this professional stage shifted their foundational pedagogical beliefs through applications from the text by Marcia Tate called *Sit and Get Doesn't Grow Dendrites*. A primary theme of the text is that adult educators (like K-12 students) are not perceptible to learning through repeated lecturing. For professional development to be effective educators they need to actively engage with one another for professional development (Tate, 2012).

The lead organizer then joined a school committed to the curricular design of utilizing PBL across subject areas. The lead organizer was able to see how rich and conducive learning could be when educators encouraged students to incorporate knowledge from science, reading, math, and the arts. In this PBL environment, they saw students connecting learning to their life experiences and making meaning of their learning discoveries. Perhaps more important professionally, the lead organizer was being encouraged to collaborate in lesson creation with educators from other disciplines and work through challenges of cofacilitating learning.

*“And in that school, we saw and approached teaching and learning as through-line questions. So how do we make learning connected so that our students are seeing that math and English and science and history and social concerns are not separate, but they all build off of another, interact with each other, and are connected and in traditional schooling it’s like you get 45 min of math, you get 45 min of the science and they never talk to each other. And at this school, there was an opportunity for kids to see and make meaning across content areas. And because of that, it really leveraged teacher collaboration so that teachers are talking to another, planning with one another, and feeling empowered to help their students make those connections.”*

The lead organizer’s professional experience at this PBL school was pivotal in their pedagogical development and aligned closer to the GSMT philosophical underpinnings. The impact of the lead organizer’s time at this PBL school influences how the Schoolyard Network format is interactive and engaging for educators. The Schoolyard Network consistently provides educators an opportunity to collaborate with peers, adapt teaching strategies, and actively partake in building lessons.

#### 4.1.3. Evolution of STEM

The lead organizer changed their interest and effort in teaching STEM over their career, initially funneling towards the pathway of English, creating a sensitivity and awareness to supporting female students to enter STEM fields. Because of their firsthand experience being funneled away from a STEM career, programming decisions for the Schoolyard Network are careful to consider how student groups, especially those underrepresented in STEM fields, are being supported throughout activities.

*“But everybody was like, you’re a good reader and writer like you should, like, go into English. And so I just listened to that because that’s what I was like told I was good at. So, but I never loved it. I never felt in those classes the way I saw other students feel in those classes, but in my science classes, I felt that excitement.”*

#### 4.2. Lead Organizer’s Vision for the Future

The lead organizer is currently mentoring a new cofacilitator. In a similar manner to how our lead organizer became the Schoolyard Network lead, the organization looks to cultivate multiple leadership positions to ensure a system is in place to help the Schoolyard Network function beyond one individual. Cofacilitating provides opportunities for reflection on sessions and planning conversations.

*“I think it’s important that we build systems and not just people.”*

*“And so we have those conversations in our reflection time of like, what did we think went well? What do we want to think about next time? to give her space to grow as a facilitator.”*

##### 4.2.1. Cofacilitator Development

Although there are some constraints (i.e., time, other work demands) and guidelines (i.e., teaching experience) on decisions and how leaders are selected for a role in running the

Schoolyard Network and GSMIT programming, there is clear intent by GSMIT leadership to provide faculty with decision-making power in their programming. In order to grow the Schoolyard Network, guidance from the other cofacilitator is provided, focusing on three major themes that function like support-structures to prioritize teacher autonomy in PD: (1) be who you are, (2) have a multi-tiered timeline woven into a North Star vision, and (3) provide clear directives across cofacilitators during Schoolyard Network sessions.

*“You have to kind of try on what feels right and what feels right might not be what you thought . . . it would be at the beginning.”*

*“At the call at the activity level, at the call level, at the yearlong planning level, and at the multiyear long planning level like we do regardless of how we facilitate need to know where we’re headed and why and let that be the guiding like North Star of you know making all the decisions in the in between.”*

*“Whether it’s kids with behavior or adults with confusion, like a lot of that is born out of gray space. So, if we can eliminate the gray space with the clarity of the directions we’re giving, we’re setting all people up for success, and that can take practice too.”*

#### 4.2.2. Collaborating Through the Schoolyard Network Identity

The Schoolyard Network lead organizer understands the importance of collaborative efforts with key entities in the surrounding community. Day-to-day interactions regularly involve colleagues collaborating authentically, creating a workplace environment that can prioritize educators and students who visit GSMIT. All GSMIT staff are unique in their interests and expertise; for instance, some are naturalists with degrees in biology and others, like our lead organizer, majored in fields like English or education. This allows the lead organizer to rely on different members of the GSMIT staff for a wide range of projects. Most commonly, the lead organizer will utilize certain individuals as “thought partners” for planning or adapting within the Schoolyard Network. The cultivation of relationships provides the backing for authentic interactions and better programming.

*“We always like call it watercooler talk, sometimes the most valuable things you get out of an experience are during that watercooler talk time because you have this question and you are talking and walking with this other person that you can ask it to or you heard them say something that was really inspiring to you or that you want to try.”*

Fostering collaboration with like-minded external organizations is valued by GSMIT and provides a support system for the lead organizer. For example, GSMIT participates in the Knox Outdoor Learning Coalition which brings together over 35 organizations from Knoxville (e.g., the Knoxville Zoo, the Botanical Gardens, the University of Tennessee Gardens, etc.) who all aspire to involve kids in outdoor education. A primary goal of the Knox Outdoor Learning Coalition is to collaborate, streamlining programming for the community and eliminating overlapping programming. However, participating in the Knox Outdoor Learning Coalition also provides the lead organizer a chance to interact with leaders from similar organizations and self-reflect on the programming of the Schoolyard Network.

#### 4.3. Schoolyard Network Design

The Schoolyard Network sessions are educator centered at the core. Session pacing decisions were consistently adjusted based on feedback from attending educators. During a PLC session, attendees regularly feel autonomy over their decision-making as they participate, connect, and reflect.

#### 4.3.1. Rich and Meaningful Collaboration Through Active, Responsive Listening

Although Schoolyard Network sessions are virtual, the lead organizer engrains peer interaction into each inquiry-style session. Perhaps a distinguishing aspect of this PLC is the lead organizer structuring inquiry-style collaborative sessions while focusing intensely on attending educators and actively responding depending on circumstances. This relationship-driven characteristic of the Schoolyard Network works contrarily towards striving to meet each session's content and pedagogical development outcomes, but seems to provide the deeper identity support educators are searching for in the PLC.

*"And sometimes, like people, whether it's a teacher or not, need just somebody to listen. And like affirm and nod and like, give that active listening body language. Sometimes people need a coach where you are helping them, like, come to an answer. But they have the answer in their brain and you're asking questions to help them pull that answer out. And they are like solving their own problem through that process. And sometimes people need to consultant. Sometimes you're just like I need the answer. I want you to give me the answer. Like, what would you do?"*

Participants communicate, collaborate, and problem solve through a variety of pedagogical techniques throughout each session. The introductory period includes separating into small groups for meaningful introductions to build multisession relationships. There is also space for educators to celebrate the successes of one another and share challenges they are experiencing at school during the first fifteen minutes. Once the main exploration portion of the session begins, one of the Schoolyard Network leaders will pose deep-thinking questions to the participants, who are paired in "breakout rooms" to collaborate through the answers. Leaders will rarely share personal responses or answers with participants as the leadership team believes that would rob them of their opportunity to learn. Allowing participants to work through questions together cultivates peer-to-peer understanding and self-efficacy across the PLC.

Active, responsive listening by the lead organizer extends beyond sound during Schoolyard Network sessions with their careful use of the chat feature online to include and build up individuals during sessions. Chat features are not commonly used as a technique to connect with session participants, build relationships, and monitor mental health of participants, but in this PLC this technique is frequently implemented.

*"What everybody else can't see is that I have the chat open the whole time. And so oftentimes I'm chatting one on one with people in the group and they will I be like, hey, just checking in like or it's nice to see you. And even just like that greeting or that like that invitation into this space will later lead to, like actually had this question that I didn't want to ask whole group and we're like typing about that back and forth."*

A regular action the lead organizer used before sessions started was as educators joined, they were greeted and asked about their personal well-being. Often these greetings include personal connections to family activities, classroom experiences, or interests. Not only do these conversations demonstrate the lead organizer's desire to build connected relationships with participants, but they can also serve as a touchpoint for the lead organizer to better understand the day-to-day struggles educators are facing. There are further opportunities to cultivate participant-driven discussion opportunities as each session officially starts, where educators are encouraged to share their challenges, successes, and questions. Carefully designing this time as an "invitation" with the group provides the opportunity for educators to approach the PLC at their own pace.

*"I'm inviting you to do this . . . that in that intentional language of invitation. It is born out of really valuing that people feel seen, that we care about what they say and what they're sharing."*

#### 4.3.2. Persistently Adapting to Educator Needs

Since its conception during the COVID-19 pandemic, the Schoolyard Network continues to adapt to match the ever-changing realities of educators. At the beginning of lockdown, educators had to provide virtual learning opportunities for their students. Eventually, this evolved into a hybrid mode of in-person and virtual education before finally moving back to completely in-person classrooms again. Before the current lead organizer of the Schoolyard Network began facilitating sessions, the initial leaders were mainly concerned with addressing the need at the time, providing outlines of outdoor STEM lessons that educators could use with their students in a virtual space. These lessons were “grab-and-go” style templates that educators could quickly take from a Schoolyard Network session and use in their virtual classroom. For example, a lesson called “My Secret Plant” was used where students would explore their own outdoor space to find a special plant and draw a map describing where the plant was located. Then, students pair and search for the plant with the map and discuss distinguishing characteristics of their plants and overall environment.

When the lead organizer was hired at GSMIT, they spent a few months cofacilitating the Schoolyard Network with the original leaders. During this cofacilitation period, they gained an understanding of the help educators needed as well as an appreciation for the session structure the original leaders established. As they began facilitating on their own, they maintained the same structure as before, but felt that as the pandemic regulations eased, educators had less need for “grab-and-go” activities and were asking for more understanding of outdoor and experiential inquiry learning. The “My Secret Plant” lesson discussion was changing; educators now discussed deeper aspects of the lesson, such as integrating different subject areas into the “My Secret Plant” lesson, and differentiating based on grade level or ability. Some participants were comfortable enough now with the concepts being discussed that they began writing their own outdoor learning lessons.

In its current form, the Schoolyard Network continues to grow towards having deeper pedagogical discussions about outdoor and STEM education. The lead organizer explained that the pedagogical shift is driven by questions coming from educators, such as the following:

*“What kind of feedback do I give a struggling student on this activity?”*

*“How do I encourage my students to ask deeper questions that push their thinking?”*

During one Schoolyard Network session a pedagogical question caused the session to run for an additional 20 min, demonstrating participants’ deep-interest in pursuing pedagogical conversations. These teacher-driven actions provide evidence of why the Schoolyard Network continues to develop into an exemplary outdoor PLC.

The Schoolyard Network has other feedback mechanisms besides the in-person, organic feedback including an April annual survey. One adjustment the annual survey feedback suggested was to update the cohesive, annual design of sessions to change based on educator needs during different times of the school year. For example, at the beginning of the academic year, the Schoolyard Network sessions typically discuss setting boundaries in an outdoor classroom or how to facilitate outdoor learning activities easing students into the new outdoor learning environment. Lessons discussed early in the year are designed to be facilitated in a way that sets students up for success, builds stamina in the outdoor learning context, and allows educators to practice class routines before experiences become more complex. By the end of the year, educators are comfortable with outdoor management routines, so Schoolyard Network session designs shift to conversations about educational theory and deeper nuances of the inquiry learning cycle. With consistent adjustments over the year based on the needs of the PLC, the Schoolyard Network provides a thought-

ful design to understanding how to support educators through a series of professional development sessions.

Perhaps the most poignant Schoolyard Network adjustment was the response to educators wanting to see each other's schoolyards and celebrate the end of the series of sessions with an in-person event called the Schoolyard Escape. During the Schoolyard Escape, participants travel to the same schoolyard to interact in-person to design and analyze curricular experiences they could plan in this unique setting. The Schoolyard Escape is a relationship building event that provides different professional sessions where educators put on the learner's hat and self-select sessions based on experience with outdoor learning, content area expertise, or perhaps another factor to help deepen conversations. During an interview, the lead organizer described the connectivity of the Schoolyard Escape as follows:

*"We met each other in person this summer, and they didn't know each other before the Schoolyard Network. Had never talked, never met, they didn't even live in the same state. And then, (they) decided to meet up over the summer to hang out in person."*

The Schoolyard Escape is developing into another extension of this PLC that is deepening relationships for monthly meetings and providing more confidence for educators to voice and support each other during PLC sessions. Schoolyard Network sessions regularly and purposefully build in time for educators to have a voice and support each other in their challenges. During this "parking lot time", if a participant voices their struggles with classroom management in their outdoor classroom, other participants will have the opportunity to respond with strategies that have worked in their experiences. With a structure of weaving in-person events with Schoolyard Network sessions, the professional development series is noticing participants reaching out to each other more for support and growth as PLCs should function.

If the lead organizer does not hear from a specific participant in the initial greetings or during parking lot time, they will typically message the participant in the chat to understand any potential gaps in their learning. If a participant reveals a misunderstanding or point of confusion, the lead organizer will typically pause the whole group conversation to discuss the topic highlighting the obstacle. In PLCs, it is common for many people to experience a similar struggle but be hesitant to show misunderstandings broadly.

*"We built in the parking lot time at the end because I was feeling disconnected with some of the participants. And I'm like, I don't really know where like in what sense are you feeling good about taking this and putting it into practice? And where are you feeling hesitant or what things are top of mind for you right now?"*

#### 4.3.3. Mindfulness

Teacher workload demands are intense. To address the need for a mental reset, the lead organizer has maintained the tradition using a mindfulness moment near the beginning of each session. A mindfulness moment within the scope of the School Yard Network can appear in different forms, but all revolve around ensuring that participants feel present and connected to the shared space.

*"So recognizing that regardless of what you're day has looked like, there's just a lot of noise happening for all of us, whether it's in our own lives or things happening in the world. Your to do list is like constantly growing so giving people the permission and inviting them to connect with themselves and release the day so that they feel like they can be fully present with the next hour and a half that lies in front of them, with the people that are there and the things that they're going to be doing. I have heard a lot of feedback of just how nice that feels, how powerful it is. Oftentimes you can see the difference in demeanor even on screen of like pre-mindful moment and post."*

An example of a mindfulness moment is when the lead organizer asks participants to shut their eyes and focus on the different senses they are using and what is happening with them. For example, the lead organizer may ask participants to focus on five things they can feel, four things they can smell, and so on. The aim of these simple exercises is to “declutter” the minds of busy educators, allowing their minds and bodies to be fully present during each PLC session. From the perspective of the lead organizer, there is a significant difference in body language and engagement before and after the mindfulness moment. Pausing and providing educators with selfcare time may seem like it is in a juxtaposition with accomplishing the learning outcomes and content goals for the session, but the pause seems to reset educators and provide the PLC cofacilitators with opportunities to be present at that very moment with participants. By weaving together selfcare strategies and usable lessons, participants see the benefit of dedicating time to the Schoolyard Network.

*“Teachers say, like I didn’t know how badly I needed this. Like I’m leaving here with ideas for my classroom, and also I’m leaving here feeling like I have a had a reset as a human and we value those things equally because it’s like we can only be as good of teachers as we feel. And so valuing the whole person not just that career aspect of person is really important in trying to be intentional with that.”*

#### 4.3.4. Inquiry Cycle

The Great Smoky Mountains Institute at Tremont aligns many of its instructional practices with the Better Environmental Education, Teaching, Learning, and Expertise Sharing (BEETLES), a collection of educators committed to improving the quality of outdoor and experiential education. The BEETLES organization is committed to researching how students best learn through outdoor environments. Among the most critical qualities of successful outdoor learning experiences are lived experiences, prior knowledge, and constant discourse (The Regents of the University of California, 2024). To create an accessible model for educators to follow, BEETLES created a learning cycle that includes five phases: invitation, exploration, concept invention, application, and reflection. BEETLES also provides educators with resources to implement productive discussion throughout lessons (Sassi et al., 2013). Each phase allows students to connect with the targeted concept in a different way, pushing students to continue making discoveries and challenging their initial viewpoints.

*“I love that we are working with this inquiry framework because it is applicable no matter what you’re teaching. Like inviting kids into a learning experience, encouraging them to get curious and tap into background knowledge, exploring and asking questions and struggling through something that you don’t quite, you don’t quite get yet. And then making time for reflection. If we could all do that in our teaching and think about teaching experiences, learning experiences, in that way, I think that is a step forward.”*

Schoolyard Network sessions follow an abbreviated version of the BEETLES learning cycle, modeling for educators how to use the learning cycle within a constrained timeframe. The lead organizer breaks the session into three connected arcs, labeled Invitation, Exploration, and Reflection. The first 15–30 min of each session is the “Invitation” portion of the learning cycle, where educators are introduced to each other, undergo a mindfulness exercise to focus their attention, and have open share about their outdoor experiences. By actively choosing to be a member of a learning exercise, the lead organizer observes learners “putting on the learning hat” and taking on greater responsibility for their learning. The next arc of learning takes about 45–60 min of the session which is called the “Exploration” phase. During this phase, the lead organizer will ask participants to go into their own outdoor space and complete an experiential learning activity. Participants have a combination of personal working time and collaborative work to ensure participants are

creating their own understandings and sharing their findings with others. The third arc or “Reflection” wraps up the cycle, taking between 15 and 20 min, and allows participants to fully discuss their takeaways from the learning activity. During this time, the organizer will ask participants questions, providing wait time to answer in a small-group or whole-group setting. This facilitation technique called a “culture of talk” encourages instructors to use broad questions that cultivate an environment that encourages students to listen deeply to their peers and share their own ideas (The Regents of the University of California, 2024). A key to successful Reflection times is having participants push answers to the open-ended questions that can have multiple different “correct answers”. The Reflection time created a highly interactive discussion environment for the Schoolyard Network facilitating conversations where many participants are open to sharing their discoveries and wonders.

*“A broader philosophy that I would say I aligned with at Tremont in that there is a quote that says, “when you teach someone something, you are robbing them of the opportunity of learning it.”*

## 5. Discussion

The impact of the COVID-19 pandemic presented drastic challenges for educators, shifting the method of instruction swiftly and causing stress on educational systems across the world (Pokhrel & Chhetri, 2021; Sahu, 2020; Tarkar, 2020). However, some initiatives like the Schoolyard Network that were born out of this time now positively impact educators and provide new, unimagined support. The Schoolyard Network has now grown into an online, convenient support system with over 300 registered members and around 20 regular attendees at PLC sessions. This article presents findings from a key case study with detailed information about the identity, attributes, and role of the lead organizer of the Schoolyard Network. Interestingly, the lead organizer’s view of STEM content was thought to be the cornerstone of decision making for planning sessions because clearly content plays a vital role in teaching and changing the state of education (CoSTEM, 2018). However, at the end of this research study, it was clear that four other attributes took precedence in many decisions that had to be made and STEM content functioned as a backbone, or foundational precursor to prioritize these attributes:

- Prioritizing rich and meaningful collaboration through active, responsive listening;
- Persistently adapting to educator needs;
- Utilizing mindfulness techniques;
- Delivering session material through the inquiry cycle.

These attributes support teacher development in understanding how to implement outdoor inquiry-styled STEM lessons while prioritizing participants. The organization structure, though focused on delivering inquiry-based outdoor lesson opportunities which are effective in professional development (Darling-Hammond et al., 2017b), prioritized opportunities for educators to participate, share, and reflect about the challenges that are unique to the field of teaching (Yli-Panula et al., 2023).

This theme of mindfulness provides a gateway to conversations about inquiry outdoor STEM education, dependent on the participant’s needs, providing a flexible session structure that could be an opportunity for growth in content knowledge or mental health development depending on each educator’s unique situation. Educators are unique human beings in one-of-a-kind situations and are growing in their own emotional competence in teaching and retaining key information from educator professional development (Madalinska-Michalak, 2015). Given case study research is readily accepted as a methodology that offers unique, in-depth, holistic insight into a specific phenomenon, but lacks generalizability and replicability (Drew, 2023) the Schoolyard Network’s story can be helpful if repurposed by other aspiring PLC organizers impacting local educators in other

locations. There are a few key lessons this research suggests prioritizing to cultivate a productive, impactful environment:

- Lead organizers of PLCs should provide in-person opportunities that can help build relationships, grounded in an organization's mission and philosophy. From the lead organizer's perspective, there was a clear connection in attending in-person events (i.e., the Schoolyard Escape), for multiple reasons including how visits to GSMIT helped educators engage in the professional development on a deeper level, but also to prioritize utilizing local places and investigations (Bocko et al., 2023).
- There is a palatable difference between inquiry-based virtual instructions and lecture-driven methods, both in what content is retained by participants and the impact on participant well-being (Pinheiro & Alves, 2024). As PLC session design decisions are made, finding places to have participants "put on the learner hat" should be prioritized.
- Organizers should intentionally develop a structure with multiple cofacilitators, ideally tiering leadership based on experience, attributes, and training as research suggests (de Jong et al., 2023). Staggering experience levels within the program so that cofacilitators not only understand the direction of the program but more importantly, connect with regular participants during sessions is essential to maintaining a virtual environment that educators will continue to join, even during the busiest months of the year.
- Providing the PLC's educators the opportunity to rethink instruction outside provides unique pedagogical opportunities that are hard to create inside a school. PLC organizers should consider using alternative, appealing, and convenient environments for sessions.

If our schools are going to continue to recognize the social and cultural needs for expanding outdoor education (Aasen et al., 2009; Correia et al., 2024) to meet the variety of evolving needs of students (Elias et al., 2003; Largo-Wight et al., 2018), PLC's need to creatively meet educator's given their hectic lifestyles. With flexible virtual and in-person programming, the Schoolyard Network provides a user-friendly method of delivering meaningful, consistent teacher professional development. The lead organizer of the Schoolyard Network is a critical decision maker in the pedagogical choices and session adjustment decisions that make PLC sessions successful for participants. But each educator impacted by the Schoolyard Network has a more critical role; educators have the unique opportunity to become powerful proponents of outdoor programming choices with their own students and with peers across school networks.

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