7th International Instructional Technologies in Engineering Education Symposium

PROCEEDINGS OF THE

7TH INTERNATIONAL INSTRUCTIONAL TECHNOLOGIES IN ENGINEERING EDUCATION SYMPOSIUM

9 October 2025, Izmir, Türkiye

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VILLAGE
Virtual Innovative Learning Laboratories for Global Engineering Education

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OFFICIAL DECLARATION REGARDING SYMPOSIUM STATUS

The organising committee of the 7th International Information Technology and Engineering Education Symposium (7th IITEE) hereby certifies the official participant demographics for the event. Based on the final presentation records, a total of 250+ participants and 69 presenting authors delivered papers at the congress, comprising 37 international and 32 domestic (Turkish) presenters.

Consequently, **the proportion of international participants** is calculated at approximately **53.6%.** This figure exceeds the 51% threshold, thereby officially designating the 7th IITEE as an **"International" scientific event** in accordance with academic criteria. This high ratio of global representation underscores the congress's commitment to fostering cross-border scholarly exchange and maintaining rigorous international standards in the fields of information technology and engineering education.

The Organizing Committee

SYMPOSIUM PROGRAMME

Time	
09:00–09:30	***Registration***
09:30–09:45	***Opening Ceremony***
09:45–10:00	*"Virtual Innovative Learning Laboratories for Global Engineering Education (VILLAGE)" Project* ***Coordinator: Fırat SARSAR***
10:00–10:45	***Keynote Speaker*** ***From Programmes to People: An Ecosystem Approach to Quality Assurance*** Prof. Dr. José Carlos Lourenço QUADRADO *The President, European Network for European Accreditation of Engineering Education (ENAEE)*
10:45–11:15	***Coffee Break***
	SESSION 1 **Chair: Assoc. Prof. Dr. Aylin Şendemir**
11:15–11:30	*A Review of the VILLAGE Project and Analysis of Score Ranking in Instructional Design Models* *Fırat SARSAR, Özge ANDİÇ-ÇAKIR, Makbule BAŞBAY, Ninel ALVER, Aylin ŞENDEMİR, Gizem ENGIN, **Mehmet KARA**, Gökhan GÜRBÜZ, Miša CAJNKO, Matic PALVIN, Christos VASILAKIS, Saqib CHAUDHRY, Kapal DEV, Linda PAVITOLA, Valdis PRIEDOLS, Anita JANSONE, Nida ŞENSOY MERCAN, Manon van LEEUWEN, Viktor MILOSHEVSKI, Urfan TAGIYEV, Sima MAMMADOVA*
11:30–11:45	*Developing Sustainability-Focused Entrepreneurship Competencies in Engineering Education: The Greenathon Example* *Elif TUNALI ÇALIŞKAN, **Özge ANDİÇ-ÇAKIR**, Fırat SARSAR*
11:45–12:00	*The Effect of a Professional Development Workshop on Faculty Members' Technological Pedagogical Content Knowledge Self-Efficacy Perceptions and their Cognitive Structures* ***Bahadır NAMDAR,** Hüseyin Ekrem ULUS, Setenay SÜRMELIOĞLU, Linda PAVITOLA, Ivita PELNENA, Nicolay MIHALOV, Boris EVSTATIEV, Tsvetelina GEORGIEVA, Seher KADIROVA, Atanas ATANASOV, Tzvetelin GUEORGUIEV, Danguolė BYLAITĖ-ŠALAVĖJIENĖ, Leta DROMANTIENĖ, Ayşe Saliha SUNAR, Vedat TÜMEN, Nilay BOZKURT, Manon VAN LEEUWEN, Karl DONERT*
12:00–13:15	***Lunch Break***
13:15–14:00	***Keynote Speaker*** ***Building Bridges for Researchers: Horizon Europe and Marie Sklodowska Curie Actions*** Şeyma SAYIMLAR *National Contact Point for MSCA & EURAXESS National Coordinator, TUBITAK*

SESSION 2 Chair: Assoc. Prof. Dr. Alev Ateş Çobanoğlu	
14:00–14:15	*Implementing Sustainability in Textile Engineering through Service Learning: A Case Study of the Sustainable Knitting Lab* *Anne-Marie GRUNDMEIER, **Mustafa ERTEKİN**, Gözde ERTEKİN, Arzu MARMARALI, Manuela BRÄUNING, Matejka BIZJAK, Mirela BLAGA, Zlatina KAZLACHEVA*
14:15–14:30	*Evaluation of the Need for Digital Twin Technology in Civil Engineering for Climate Resilience* ***Taylan GÜNAY**, José Carlos QUADRADO, María José Bohórquez SANTOS, Manon van LEEUWEN, Setenay SÜRMELİOĞLU*
14:30–14:45	*Innovative Technologies for Plant Protection in Irrigation and their Application in Education* ***Huseynov Elvin ELKHAN**, Mammadzade Vagif AGIL, Vagifli Fuad AZER*
14:45–15:00	*Emerging Competencies in the Logistics Sector in the Context of Digitalization in Sustainability: Analysis of Turkey Case Studies from the EARTH Project* ***Hakan ERKAL**, Ali Erhan ZALLUHOĞLU, Burcu ARACIOĞLU, Magdalena MALINOWSKA, Katarzyna ŁOBACZ*
15:00-15:15	Innovative Curriculum to Evaluate Marine Fishery Discards as Raw Pet Food - MARIPET **İlker AYDIN**, Özgür ALTAN, Tatjana DOBROSLAVIĆ, Vlasta BARTULOVIC, Dimitris KLAOUDATOS
15:15–15:45	***Coffee Break***
16:00-17:30	**Annual Meeting of Virtual Innovative Learning Laboratories for Global Engineering Education (VILLAGE) Project**
SESSION 3 Chair: Dr. Miray Emreol Gönlügür	
17:30-17:45	***Online*** *Curriculum Development for MakerLabs: A Literature Review* *Fırat SARSAR, Özge ANDİÇ ÇAKIR, Alper BAŞBAY, Mutlu BOZTEPE, Hayal BOYACIOĞLU, Barış Oğuz GÜRSES, **Sercan SABANCI**, Beyza YEĞEN*

CONTENTS

"Virtual Innovative Learning Laboratories for Global Engineering Education (VILLAGE)" Project

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ABSTRACT

The objective of VILLAGE is to reassess the post-pandemic pedagogical processes and requirements of engineering educators and students regarding laboratory practice within a multidimensional, multicultural, and multidisciplinary framework. It seeks to establish roadmaps for innovative instructional design models that align with stakeholder perspectives, aiming to develop effective and sustainable educational models while creating a pilot virtual laboratory and its accompanying learning materials VILLAGE is a collaborative research and innovation (R&I) initiative focused on developing a sustainable learning model for laboratory engineering education, addressing contemporary challenges and instructor requirements through staff exchanges among university partnerships, research infrastructures, and SMEs in Europe and beyond, with the objective of enhancing inter-sectoral and international collaboration. Virtual laboratories for engineering education are generally recognised to exist, and some factors are employed efficiently. Beyond the current state of the art, this project intends to create a sustainable paradigm for engineering lab instruction based on a multifaceted, multicultural, and multidisciplinary study, in addition to creating another virtual lab.

Keywords: *Engineering education, instructional design, virtual lab.*

OVERVIEW OF THE VILLAGE PROJECT

VILLAGE is a joint research and innovation (R&I) project funded under MSCA-SE programme. Project consider the needs of the instructors and students with the exchange of staff within partnerships of universities, research infrastructures and SMEs in Europe and beyond, which aims to strengthen inter-sectoral and international collaboration. The VILLAGE project consortium structure is presented in Figure 1. The partner structure comprises a total of 9 partners from 8 different countries.

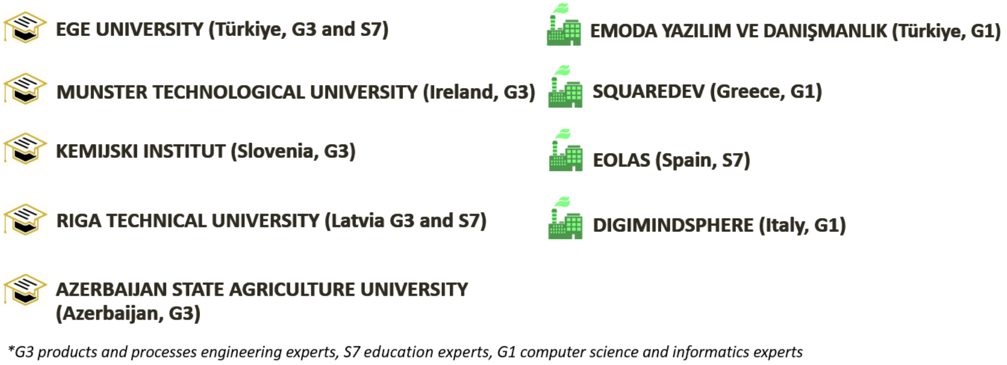

Figure 1. VILLAGE Project Consortium Structure

Virtual Innovative Learning Laboratories for Global Engineering Education (VILLAGE) aims to;

- re-examine the post-pandemic teaching processes,
- understand the needs of engineering instructors and students for laboratory practice in a multidimensional, multicultural and multidisciplinary context,
- determine roadmaps to create effective and sustainable instructional design models in line with the opinions of the stakeholders,
- develop a pilot virtual lab and its learning materials and test the proposed model.

The duration of the VILLAGE project is 48 months in total. The project consists of 6 work packages: 3 research work packages (WP1, WP2 and WP3) and 3 supporting work packages (WP4, WP5 and WP6). The details of the work package are shown in Figure 2.

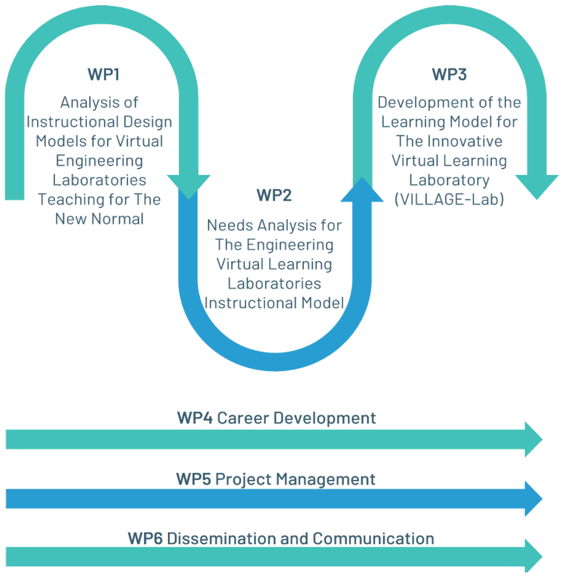

Figure 2. VILLAGE Project Work Packages

A total of 32 months has been completed in the 48-month project timeline. Deliverables submitted during this period are presented in Table 1. Project deliverables with a dissemination level of 'PU-Public' have been shared openly on the project website (https://www.thevillageproject.eu/) and the Zenodo platform (zenodo.org/communities/villageproject).

Table 1. VILLAGE Project Submitted Deliverables

Deliverable No	Deliverable Name
D1.1	Global State of The Art Report (VILLAGE Consortium, 2024a)
D1.2	Open Access Database of Instructional Design Models (VILLAGE Consortium, 2024b)
D1.3	Score Ranking of Instructional Design Database (VILLAGE Consortium, 2024c)
D1.4	Report on Deficiencies in Instructional Design Models (VILLAGE Consortium, 2024d)
D2.1	Requirements and Needs Analysis Methodology (VILLAGE Consortium, 2024e)
D2.2	Needs Analysis Report of Instructors (VILLAGE Consortium, 2025a)

ACKNOWLEDGEMENT

The VILLAGE (Virtual Innovative Learning Labs for Global Engineering Education) project, funded by the European Union under the Horizon-MSCA-2021-SE program (Grant Agreement No. 101086464). The authors would like to thank all project partners for their collaboration and contributions to the development of sustainable and inclusive virtual learning environments in engineering education.

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VILLAGE Consortium. (2024a). D1.1 – Global State of The Art Report. Horizon Europe Project No: 101086464. https://doi.org/10.5281/zenodo.15288449

VILLAGE Consortium. (2024b). D1.2 – Open Access Database of Instructional Design Models. Horizon Europe Project No: 101086464. https://doi.org/10.5281/zenodo.15288506

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VILLAGE Consortium. (2024d). D1.4 – Report on Deficiencies in Instructional Design Models. Horizon Europe Project No: 101086464. https://doi.org/10.5281/zenodo.15288522

VILLAGE Consortium. (2024e). D2.1 – Requirements and Needs Analysis Methodology. Horizon Europe Project No: 101086464. https://doi.org/10.5281/zenodo.15288533

VILLAGE Consortium. (2025a). D2.2 – Needs Analysis Report of Instructors. Horizon Europe Project No: 101086464. https://doi.org/10.5281/zenodo.15288541

KEYNOTE LECTURE —From Programmes to People: An Ecosystem Approach to Quality Assurance

José Carlos Quadrado

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ABSTRACT

This keynote explores how solid quality practices and educator professional recognition accelerate the effective use of instructional technologies in engineering education. The EUR-ACE accreditation program (Europe's outcome-focused, ESG-compliant reference) was briefly introduced as a pragmatic global framework that supports the continuous improvement, transparency, and international recognition of engineering degrees. Furthermore, ENTER International Professional Engineering Educator Registration, an international framework and registration system that recognizes educators' competencies through evidence-based portfolios and continuous professional development, was introduced. ENTER's competency model was examined in terms of how it complements EUR-ACE® by developing teaching capacity, encouraging innovation in digital and active learning, and linking faculty development to program outcomes and evaluation cycles. In summary, it was demonstrated how existing programs and people are moving together towards effective and globally recognized engineering education.

KEYNOTE LECTURE — Building Bridges for Researchers: Horizon Europe and Marie Sklodowska Curie Actions

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ABSTRACT

During the keynote presentation, the Horizon Europe Programme was introduced as a seven-year (2021–2027) research and innovation initiative with an estimated budget of €95.5 billion. The programme's structure was explained to consist of three main pillars: Excellent Science, Global Challenges & European Industrial Competitiveness, and Innovative Europe. The importance of the Marie Skłodowska-Curie Actions (MSCA) under the Excellent Science Pillar was highlighted, emphasizing how they empower researchers through mobility and training across five different actions. Applications were indicated to be submitted online via the Funding & Tender Opportunities Portal. The Gender Equality Plan (GEP) was mentioned as a mandatory requirement for specific public institutions in EU Member States and Associated Countries, effective from January 1, 2022. Finally, TÜBİTAK Support Programs were presented as tools designed to foster and strengthen the success of the national research ecosystem.

A Review of the VILLAGE Project and Analysis of Score Ranking in Instructional Design Models

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ABSTRACT

The VILLAGE project, funded under the Horizon Europe MSCA Staff Exchange programme, aims to revolutionise post-pandemic engineering education by developing innovative virtual labs and instructional design frameworks. This paper presents a systematic search and quantitative ranking of instructional design models (IDMs) to assess their usefulness and applicability in contemporary engineering education. An initial list of 60 IDMs compiled in the project's open-access database was subjected to expert pre-screening to select 17 models best suited to the ecosystem of engineering education. The 17 models were then ranked through a score-ranking survey constructed on 12 criteria, rankings being conducted by 20 experts representing the academic and industry stakeholder communities. The analysis reveals that the top overall rankings were achieved by the Instructional Design Model for Unified eLearning, the Assure Model, Agile Instructional Design, the Kemp, Morrison, and Ross Model, and the ADDIE model.

The score-ranked database resulting from the study has been made available as an open-access dataset through Zenodo and integrated into the VILLAGE project's digital repository, thereby informing the global debate on instructional design and serving as a practical tool for educators and researchers. The study highlights the predominance of evidence-based instructional design in bridging the theoretical and practical dimensions of the engineering education domain. It underscores the role of open-access knowledge infrastructures towards facilitating sustainable and innovative practices within the field.

Keywords: *Instructional design, score ranking, database, virtual lab, engineering education.*

INTRODUCTION

The 2030 Agenda for Sustainable Development, adopted by the member countries of the United Nations, comprises the 4th Sustainable Development Goal (SDG 4), which deals with ensuring equitable access to quality education and lifelong learning opportunities for every person. The objectives include primary and secondary education, as well as affordable higher education, alongside safe, inclusive, informative, and gender-balanced learning environments. Nevertheless, the pace of the world had slowed down due to conflicts and the pandemic caused by the coronavirus (COVID-19), and thus, effective remote learning solutions were demanded. Europe invited technologies like Virtual Reality (VR), Extended Reality (XR), and immersive spaces as promising avenues to improve equality and innovation in teaching. The Horizon Europe Work Programme (2023-24) highlights the need to reach the student population with diverse backgrounds, and specifically, Virtual Reality (VR) offers the opportunity to continue education when attendance in the actual classroom is impossible (Aruanno et al., 2025). Virtual reality (VR) is gaining popularity among classroom users due to its ability to eliminate time and space limitations, as well as provide safe learning avenues. Flow-based learning is often recommended to enable students to perform better and sustain their interest in the lessons. Frameworks like "prediction-observation-examination-explanation" illustrate the relationship between self-confidence and flow when undergoing observation in online learning. X. B. Wang et al. (2022) added the Technology Acceptance Model by introducing the movement towards the stimulation of language learning. Nevertheless, the majority of virtual reality systems were based on the top-down approach, neglecting the educator's opinion, and thus require the inclusion of the educator's opinion when adopting virtual education (Liang et al., 2025).

In science and engineering education, practical skills are critical for students to apply their theoretical knowledge effectively. While traditional laboratories face challenges such as cost, safety, and limited access to equipment, researchers are increasingly exploring virtual reality (VR) as an innovative solution. VR environments provide students with a safe and engaging way to gain hands-on experience, helping to bridge the gap between theoretical concepts and practical application. This trend is a response to both technological advancements and the growing demand for skilled professionals. As a result, the need for virtual reality (VR) laboratories is increasing day by day (Yang et al., 2024).

The VILLAGE project aims to critically re-evaluate post-pandemic engineering education by examining the teaching processes and needs of faculty members and students in a diverse and multinational context. Covering seven partner countries (Turkey, Greece, Ireland, Latvia, Slovenia, Spain, and Azerbaijan), the project adopts a multidimensional and multicultural approach to analyse these needs. By conducting a comprehensive literature review and integrating qualitative data collected through focus group discussions and surveys, the project aims to develop effective and sustainable teaching models. One of the project's key components is to define a roadmap for a new teaching design based on stakeholder feedback. To test the effectiveness of these proposed models, the project will develop a pilot virtual laboratory alongside relevant learning materials, ultimately aiming to bridge the gap between theoretical knowledge and practical application (D1.1 Global State of the Art Report, VILLAGE Consortium, 2024a).

Since its inception, instructional design (ID) has been identified as a core process for organising effective learning. The profession has had an ongoing dependency on tried-and-true ID models to support both novice and veteran implementers through orderly steps such as analysis, design, development, and evaluation. Models were viewed as valuable resources for the development of sturdy education initiatives and organisational strategy impact (Stefaniak & Xu, 2020). Consequently, instructional design acts as an important link between theoretical learning and practical application to produce efficient and effective learning processes. It constitutes a systematic process containing core steps that include identifying needs, specifying clear learning goals, and determining evaluation measures to produce viable outcomes (Castelhano et al., 2024).

For this research, a new database containing the shortlisted instructional design models was compiled and made available on our website. A group of experts was used to rank 17 instructional design models to populate this database quantitatively. A selection of models from the D.1.2 (Open access database of instructional design models, VILLAGE Consortium, 2024b) database was ranked using a score survey constructed as part of the project's D1.3 (Score ranking of instructional design database, VILLAGE Consortium, 2024c) deliverable. Each record on the resultant database contains a short overview describing the model and the associated evaluation score.

RESEARCH METHOD

Workflow

The Road Map presented in Figure 1 was followed. In the first step (1), a pre-evaluation of models from D.1.2 (Open access database of instructional design models, Village Consortium, 2024) was performed to select the most relevant IDMs (Instructional Design Models) for engineering education. In the next step (2), the score ranking of selected IDMs was performed by experts. In the final step (3), the scores were evaluated.

Figure 1. Summary of the Score Ranking of Instructional Design Database Workflow (D.1.3, VILLAGE Consortium, 2024c)

Pre-evaluation of Models

First, a pre-evaluation of 60 IDMs obtained in D.1.2 (Open access database of instructional design models, VILLAGE Consortium, 2024b) was performed by EGE University. One expert from the field of curriculum development, one expert from the field of instructional technology, and one expert from the field of engineering education participated in the review process. Within the scope of the research, instructional design models that can be used in the engineering education process were examined in detail. Sixty instructional design models were identified, and their suitability for engineering education was analysed in detail by considering dimensions such as usability, student differences, suitability for the active learning process, providing feedback to the learner and teacher, and the suitability of measurement and evaluation processes to the project structure. Within the scope of the research, instructional design models that can be used in the engineering education process were examined in detail. The experts decided on 17 instructional design models that were the most suitable for this process by considering the dimensions mentioned above.

Score rankings with Experts

In this stage, EGE University developed a 12 criteria for ranking score survey based on the needs and expectation analysis derived from D.1.1 (Global State of the Art Report. VILLAGE Consortium, 2024a).

The ranking score survey consisted of the following criteria in Figure 2:

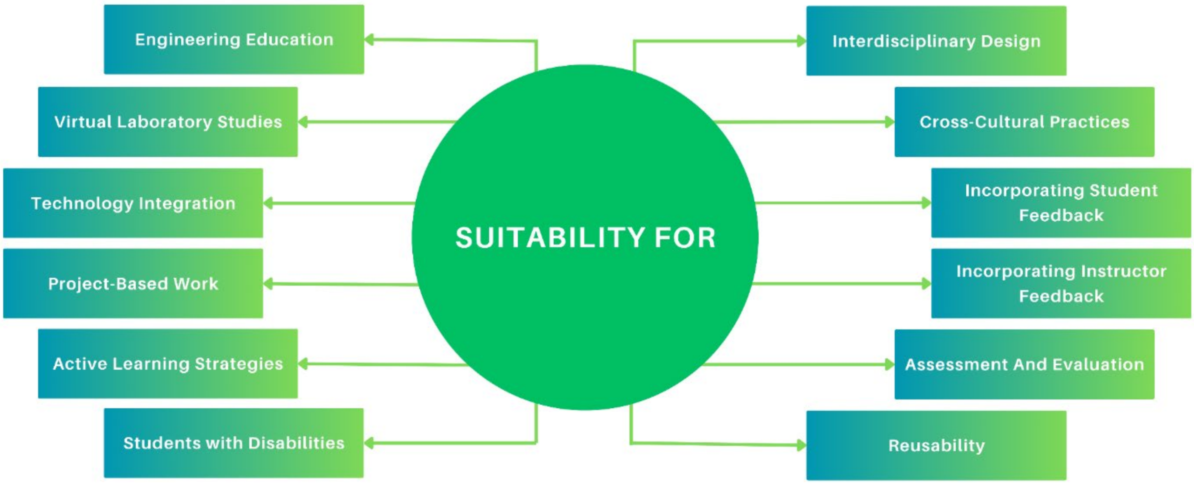

Figure 2. Ranking Score Survey Criteria

Each model was assigned a score from 0 to 3 for each survey entry (0: Absolutely not suitable; 1: Partially suitable structure; 2: Moderately suitable structure; 3: Suitable structure), resulting in a total possible score of 36 (Only integers were accepted as score values).

Experts performed a score ranking of the 17 selected IDMs. Academic partners enlisted at least three experts (if possible, one instruction and curriculum expert, one instructional technologies expert, and one field expert), while SME partners enlisted one expert (field expert). Altogether, scores from 20 experts (Instruction and Curriculum Experts, Instructional Technologies Experts, and Field Experts) for each IDM were obtained.

The preliminary score of each IDM was obtained by averaging the scores of 20 experts, and the standard deviation was calculated. Then, the scores of each IDM that lay outside of the average score ± 2*standard deviations were eliminated, and the new average value was calculated. This process was repeated until all the remaining scores lay within the average score ± 2*standard deviation.

FINDINGS

The 17 ranked IDMs are presented in Table 1 together with their average score and standard deviation.

Table 1. The 17 Ranked Instructional Design Models

IDM	Ranking (sorted from highest to lowest)
Instructional design model for unified eLearning	31.1 ± 4.5
Assure model	29.6 ± 4.9
Agile instructional design	29.4 ± 4.8
Kemp, Morrison, and Ross model	28.8 ± 4.1
ADDIE	28.7 ± 4.5
GRAPE	28.4 ± 5.8
Innovative situational model	27.9 ± 2.2
TIP model	27.9 ± 3.3
Backward design	27.5 ± 4.4
Tyler-Taba model	27.5 ± 4.7
Dick and Carey model	26.2 ± 4.7
Seels and Glasgow	25.5 ± 2.2
Demirel model	25.1 ± 4.3
Hannafin and Pack model	25.1 ± 6.6
Knirk and Gustafsson	24.3 ± 6.5
Rational planning model	22.6 ± 8.3
System approach model	22.4 ± 5.2

The list of the 17 selected IDMs was uploaded to Zenodo as a dataset along with the ranking score survey and final score rankings (https://zenodo.org/records/11401508; Figure 3). "Creative Commons Attribution Share Alike 4.0 International" was chosen as the dataset license by the project consortium.

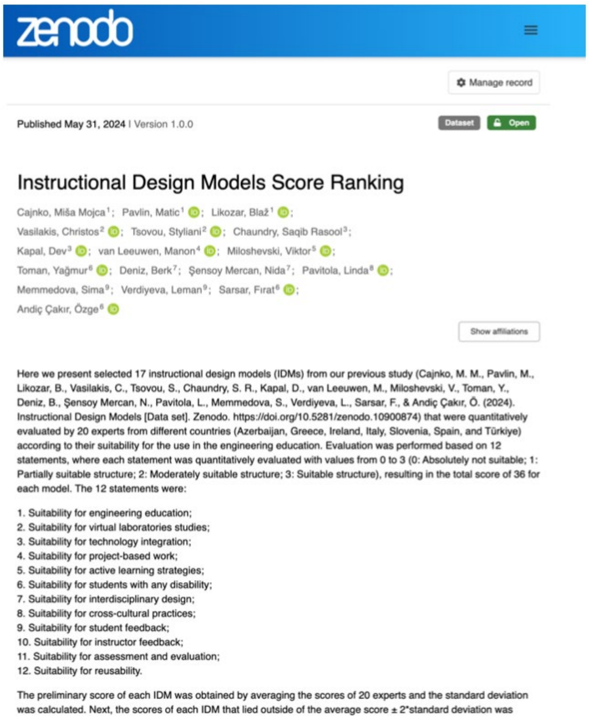

Figure 3. Ranked Instructional Design Models on Zenodo

The scoring of those 17 IDMs was also updated in the database on the VILLAGE webpage (https://www.thevillageproject.eu/idmodelsdatabase/; Figure 4). Namely, a filter button was added to the database, which enables the user to display only ranked IDMs. Moreover, each of the ranked IDMs now has a star ranking next to it (see Appendix I). Briefly, the score of each model was transformed into a percentage, which was then further transformed into a star ranking (1 to 5 stars) by dividing the percentage value by 20.

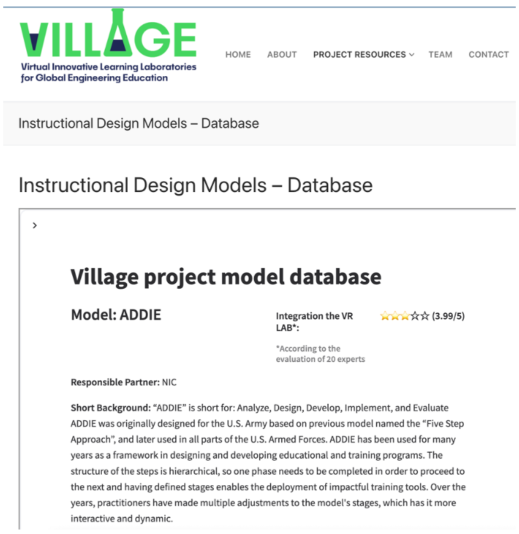

Figure 4. Ranked Instructional Design Models Database on the VILLAGE Website

The IDM score ranking database is based on the dataset uploaded on Zenodo, including all the relevant quantitatively evaluated models with their corresponding metadata (i) name of the model, (ii) short background of the model, and (iii) score ranking. To use the data on the project's website and also share it with the relevant researchers, a UI-based app was needed. For that reason, Python's Streamlit framework was selected. Streamlit is capable of helping in the development and creation of prototypes, data-sharing apps, etc., for a variety of cases. The app utilises the created dataset and provides all the relevant information in a user-friendly UI for easy access. The app has already been deployed and can be shared publicly on the web. In addition, the app has been embedded into the official Village project's website. In addition, a public repository in Git Hub has been created. Through this repository, we will track the different versions of the app and any future additions and enhancements.

DISCUSSION AND CONCLUSION

A list of selected 17 IDMs together with their score ranking was created, and they were carefully quantitatively evaluated by the expert. Evaluation was performed according to the ranking score survey that enabled the score ranking of each IDM according to its suitability for a given field/situation.

The five best-scoring IDMs are reported in Table 2, together with their score and percentage of the total score. The IDM with the highest score, 31.1 out of 36 (86.3 %), was the Instructional Design Model for unified eLearning, meaning it's best suited for engineering education for the new normal. This was followed by the Assure model (29.6 out of 36; 82.2 %) and Agile instructional design (29.4 out of 29.4; 81.7 %). Lastly, Kemp, Morrison, and Ross's model and ADDIE achieved scores of 28.8 (80.0%) and 28.7 (79.7%), respectively.

Table 2. The Five Highest-ranked Instructional Design Models

IDM	Score (out of 36)	%
Instructional design model for unified eLearning	31.1	86.3
Assure model	29.6	82.2
Agile instructional design	29.4	81.7
Kemp, Morrison, and Ross model	28.8	80.0
ADDIE	28.7	79.7

The score ranking of 17 selected IDMs has been turned into a database in the most effective way possible. This database is built on the prepared dataset and published with open access on the project website.

One of the core strengths of this work lies in the composition of the VILLAGE consortium itself, which spans seven countries (Türkiye, Greece, Ireland, Latvia, Slovenia, Spain, Italy, and Azerbaijan) and brings together both academic and non-academic partners. Multifaceted in composition, this entailed a rich diversity of experiences that ranged from pedagogic theory and research on instructional design to technology development and practical application at an industrial level. This sort of diversity served to enhance the validity of the score-ranking process itself, with models being ranked by many. Disciplinary and organisational understanding. In conclusion, the multinational and multidisciplinary nature of the consortium ensures that the findings not only accumulate within the literature base itself but also serve to construct practical, transferable, and contextually informed solutions for engineering education.

Suggestions

The findings of this research offer a worthwhile starting point towards further investigation into models of instructional design in the context of engineering education. Based on the research, the following recommendations may be made. First, it would be worthwhile for future research to broaden the pool of experts to include a wider cross-section of beneficiaries, such as students, industry professionals, and those responsible for policymaking, so that a broader range of perceptions on the adaptability of models of instructional design may be captured. Secondly, longitudinal research may be undertaken to evaluate the long-term efficacy of the top-ranked models when transferred to real-world engineering classroom and simulation laboratory settings. Thirdly, comparative research among diverse cultural and institutional settings can be undertaken to explore the possibilities of adjusting instructional design models to varied learning environments.

With respect to the prospects, the inclusion of upcoming Virtual Reality (VR) technologies into the most efficient models of instructional design presents a promising avenue. This would not only add to the immersive and interactive character of engineering education but would also bring about inclusivity and ease of access for recipients from diverse backgrounds. In this scope, the VILLAGE project presents the open-access IDMs database.

Finally, this research provides a stepping stone towards the development of sustainable, evidence-based teaching paradigms that will inform the design of next-generation learning platforms in the education of engineers.

ACKNOWLEDGEMENT

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Developing Sustainability-Focused Entrepreneurship Competencies in Engineering Education: The Greenathon Example

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ABSTRACT

Throughout history, engineering education has been structured around the transformation of technical knowledge and skills. However, environmental and social issues that have emerged on global scale today necessitate a reconsidering of the scope of engineering education. Climate change, biodiversity loss, issues related to waste management, the rapid depletion of resources and energy crisis are multidimensional and complex problems that require direct intervention from engineering disciplines. This situation necessitates that the education provided in engineering faculties be based on a holistic approach that not only focuses on generating technical solutions but also considers solutions developed within their social and environmental aspects. Traditional engineering programs prioritize students gaining skills like project management, technical analysis, and prototyping. On the other hand, contemporary approaches require engineers to also train as individuals with sustainability and entrepreneurial competencies. Hence, engineering students should have the ability to transform technical solutions that they produce into economically and environmentally viable business models. This paper outlines the main findings of Greenathon project as an example for engineering education.

Keywords: *Engineering education, sustainability, entrepreneurship.*

INTRODUCTION

Engineering education has evolved beyond being based solely on the transfer of technical knowledge; it has initiated a transformation process where students gain competencies in multidimensional thinking, critical thinking, and systemic problem-solving. This transformation is crucial for addressing complex global issues, including climate change, energy security, environmental pollution, and social inequalities. In this process, engineering faculties are repositioning themselves as centres of innovation and transformation that produce engineering solutions sensitive to society and the environment. To this end, they have begun to consider not only hard skills but also soft skills.

In this context, Triple Bottom Line (TBL) approach provides a crucial framework for integrating sustainability into engineering education. This approach aims to analyse the success of projects not only in terms of economic output but also in terms of social and environmental impacts. This approach, defined as People, Planet and Profit, enables engineering students to develop their systems thinking skills. For example, while students generate solutions to increase energy productivity, they should also consider reducing carbon dioxide emissions to protect the ecological balance. Thus, students learn to undertake a multidimensional design process that considers the social and environmental dimensions of their projects.

The TBL approach reshapes project and product development processes in engineering education. When evaluating an engineering solution, students focus not only on technical performance but also on environmental and social impacts. This enables students to gain awareness of issues such as energy efficiency, waste management, water resource conservation, and carbon emission reduction. Furthermore, projects developed within the TBL framework strengthen the ethical dimension of the engineering profession by prioritising social benefit.

Today, developing green entrepreneurship competencies in engineering education has become a core mission of engineering faculties. This approach enables students to move beyond the traditional engineering mindset, which focuses solely on technical problems. It fosters their development into individuals who generate innovative solutions to social and environmental issues. Nowadays, the promotion of energy-efficient production processes, the development of renewable energy systems, and the adaptation of circular economic practices and smart city initiatives present engineering students with opportunities to generate projects that are strong in both technical and entrepreneurial aspects. During this process, students learn not only technical design and prototyping skills, but also how to conceptualise their ideas within the framework of sustainable business models. This enables engineers to take their solutions out of the laboratory and classroom environment and integrate them into real-world problems. As a result, engineering faculties become centres of knowledge and innovation that play an active role in the sustainability-focused transformation of society.

RESEARCH AND FINDINGS

The concept of green entrepreneurship encourages engineering students to develop innovative solutions that prioritise social and environmental benefits. In this framework, engineering education should be transformed into a structure that equips students with competencies like business idea development, strategic planning, team building, market analysis and effective pitching.

The first step should be the integration of sustainability and entrepreneurship competencies into the engineering programs. But it is not sufficient to make adjustment only to course contents or programs. This process also needs project and application-based learning. Field projects where students work on real world problems, industry collaborations and community-based initiatives contribute to blending technical knowledge with social responsibility awareness. These kinds of activities equip students with skills and abilities such as teamwork, problem-solving, analytical thinking, critical decision-making, and design thinking. Furthermore, considering sustainability criteria in project evaluations helps students develop a perspective that addresses environmental and social impacts.

An engineering education integrated through real life projects helps students to transform theory into practice via field studies. For example, students designing an energy-efficient building should also focus on its social impacts, in addition to its technical efficiency. This approach enables engineering students to perform their problem-solving processes with a more comprehensive and sensitive perspective.

A good example showing how this theoretical framework is applied in practice is the Greenathon in VET

Project. This project provides a modular education and event approach developed to equip students with green entrepreneurship skills. It encourages students to develop innovative solutions to environmental problems. Although the target group for this project is vocational education teachers, trainers, and students, it was also easily applied to university students. The Greenathon project training program includes five modules that enable engineering students to understand climate change and sustainability challenges, learn about green technologies, and develop green business models.

The primary objective of Greenathon is to equip engineering students with a sustainability-focused mindset and to help them translate their technical skills into entrepreneurial projects that yield social and environmental benefits. For this reason, the training program not only provides students with technical knowledge but also offers multidimensional learning experiences through industry collaboration and real-world problems. Each module focuses on developing different competencies and forms a complementary structure.

The first module concentrates on understanding the global challenges related to sustainability and climate change. In this stage, students learn to analyse the main causes of climate change, accumulation of greenhouse gases in the atmosphere, energy consumption patterns, depletion of natural resources and biodiversity loss based on scientific data. This module establishes a solid theoretical foundation for the solution ideas that will be developed in subsequent stages.

The second model supports students by providing information on climate change mitigation and adaptation, renewable energy sources, energy efficiency, the circular economy, alternative transportation solutions, and food and nature-related solutions. In addition to this, the importance of active citizenship and ethical considerations is mentioned in this module. This allows engineering design to be integrated with environmental impacts.

The third module focuses on how technical innovations can be combined with entrepreneurial vision. Students learn about the concept of green entrepreneurship, how sustainable business models are constructed, and the role of environmental innovation in creating economic value. Skills such as market research techniques, cost-benefit analysis, and preparing investor presentations are taught. Topics like social entrepreneurship and sustainable supply chain management are also covered in this module. In addition to all this, this module includes real-world examples of green entrepreneurship and case studies. Thus, students can commercialise the technical ideas they develop and turn them into ventures that create social benefits.

The fourth module addresses the process of developing and validating ideas. In this module, students gain fundamental knowledge and skills in developing green business ideas, market research, and rival analysis. Additionally, students learn to develop and refine ideas using strategic tools such as the five whys, problem/solution tree, gap analysis, brainstorming, mind mapping, six thinking hats, and design thinking. Within this module, students also utilize strategic planning and evaluation tools such as the business canvas model, swot analysis and customer persona studies. As a result of this process, the ideas that emerge are transformed into viable and sustainable business plans.

The final module focuses on developing effective communication and presentation skills. Students learn pitch presentation techniques to effectively express their projects to investors, industry representatives and academics. Visual storytelling methods, data visualisation techniques and the use of digital tools are key components of this module. Presentations aim to strongly express not only the technical solution but also the social and environmental value of the projects.

At the end of the project, a hackathon event called Greenathon is being held in partnering schools in Europe. This event enables students to apply the knowledge and competence they have gained through modules. Teams work intensively for a determined time with mentors to develop their green solutions for global challenges and present their projects to the jury. After the pitch presentation, projects are evaluated based on technical background, sustainability impact and commercial potential criteria. The most successful projects are transformed into real-world solutions with the support of industry partners. The hackathon process strengthens students' competencies in teamwork, time management, and quick decision-making, preparing them for the dynamics of professional life.

CONCLUSION

In conclusion, the Greenathon approach offers an innovative learning model that integrates sustainability and entrepreneurship dimensions into engineering education. The project not only equips students with technical knowledge but also empowers them to transform this knowledge into solutions that yield social and environmental benefits. The five-module structure systematically aims to develop students' awareness, generate innovative ideas, and transform these ideas into viable business models. The process, supported by the hackathon event, develops students' critical skills, including teamwork, rapid problem-solving, and strategic thinking, preparing them for professional life. Thanks to a holistic approach, engineering faculties have become leading actors in sustainable development, enabling them to educate future engineers not only as technical experts but also as social green leaders.

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The Effect of a Professional Development Workshop on Faculty Members' Technological Pedagogical Content Knowledge Self-Efficacy Perceptions and their Cognitive Structures

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ABSTRACT

The purpose of this study was to investigate the effect of a professional development workshop conducted on technology-enhanced climate change curriculum that aimed to foster faculty members' technological pedagogical content knowledge (TPACK) and their cognitive structures. For this purpose, a total of 24 faculty members, from Türkiye, Bulgaria, Lithuania, Latvia, were trained at a three day-faculty training event in Latvia. The analysis revealed a statistically significant difference between the two sets of scores (W=15021.0, p<0.001), suggesting that the intervention had a measurable impact on participants' self-efficacy. The word association test results indicated increased complexity of cognitive structures, indicating that the participants mentioned subdimensions of climate change such as carbon footprint, biodiversity loss, deforestation, renewable energy and environmental responsibility after the workshop. Overall, the results indicated that the workshop had a positive impact on the faculty members' TPACK self-efficacy perceptions as well as their cognitive structures. Implications include providing explicit training on the subdimensions of climate change education, creating connections between climate change and character and values, and increasing technological pedagogical content knowledge.

Keywords: *Character and values, climate change education curriculum, cognitive structures, faculty members, TPACK self-efficacy perception.*

INTRODUCTION

Climate change is a socio-scientific issue with the most recent social and scientific foundations, emerging alongside rapidly increasing human-caused industrial and technological activity. The European Union aims to make Europe the world's first climate-neutral continent by 2050, as stated in the European Green Deal, which was announced in December 2019. Taking action to combat climate change is the responsibility of every citizen, so not only should awareness and knowledge of the issue be increased at all ages, but students should also be equipped with the skills necessary to make responsible decisions about it.

'Character and values' serve as fundamental guides for individuals to make decisions on socio-scientific issues such as climate change (Choi et al., 2011). Within the scope of teaching socio-scientific issues, three "character and values" have been defined: (a) ecological worldview (human interconnection with the environment), (b) socio-scientific accountability (engaging in socio-political action), (c) social and moral compassion (empathy and respect for others). 'Character and values' are prerequisites for responsible 21st-century individuals. Studies have shown that formal education, particularly in developing education systems, is the greatest predictor of global climate change awareness (Lee et al., 2015). However, recent studies worldwide consistently show that teachers are unprepared to teach this subject effectively (Herman et al., 2017; Oversby, 2015). Research indicates that teachers do not feel sufficiently prepared to teach this subject, often having not taken any courses on it during their university years and having taught themselves the subject (Wise, 2010). Educators' conceptual deficiencies in this area also limit the effective teaching of this subject. Furthermore, teacher candidates' inability to apply consistent moral principles in their reasoning processes leads them to exhibit limited global perspectives when using character and values in their reasoning on this subject (Lee et al., 2013, p. 925).

It is recommended that different Web 2.0 tools be used and integrated into learning processes to develop learners' 'character and values' in climate change education (Wieble, 2014). For example, Web 2.0 tools enable learners to evaluate different perspectives on socio-scientific topics such as climate change, allowing teacher candidates to participate more effectively in informed decision-making processes, share their arguments through the system, and be exposed to different viewpoints (Evagorou & Osborne, 2013). Online forum environments also enable students to participate more effectively in argumentation processes, allowing them to develop an ecological worldview that encompasses character and values (Tsai, 2018). In their research, Namdar and Topbaş (2024) observed an improvement in science teacher candidates' values of 'responsibility' towards climate change in online argumentation environments supported by different free Web 2.0 tools. Furthermore, when 29 climate change technologies and lesson plans were comprehensively examined, Bush et al. (2016) found that 'technology-based instruction shows promise in promoting strong climate change understandings when mitigating factors are addressed in the relevant curriculum' (p. 168). On the other hand, some of these technologies allow teachers to participate in collaborative decision-making processes. However, none of these curricula directly focus on developing "character and values" related to climate change. Although the benefits of Web 2.0 tools in teaching socio-scientific topics such as climate change are known, no curriculum has been found that develops character and values in this subject. Prospective teachers, who are expected to teach these topics in their future classrooms and develop lasting behavioural change in their students (AAAS, 1993), need to know which technologies to use to teach this topic, which pedagogical methods to integrate with these technologies, and have content knowledge on the subject. In other words, teacher candidates' technological pedagogical content knowledge (TPACK) must be developed for this subject (Koehler and Mishra, 2009).

Tolppanen, Kang, and Riuttanen (2022) recommend that prospective teachers be motivated to take action against climate change. However, knowledge of climate change, the complexity of the issue, and social aspects remain challenges in incorporating the subject (Tolppanen & Aksela, 2018). As a result, it is critical to identify the needs of faculty members who will incorporate climate change curricula designed to develop prospective teachers' TPACK into their future courses. To address this need, the project "Designing a Technology-enhanced Climate Change Education Curriculum (TECCHED)" was developed and funded by Erasmus+ KA220HED Project ID: 2022-1-BG01-KA220-HED-000088178. As part of the TECCHED project, this study was conducted to identify changes in faculty members' TPACK self-efficacy perceptions and cognitive structures regarding climate change education following participation in the TECCHED Professional Development Workshop.

Technological pedagogical content knowledge refers to the intertwined and intersected three sets of knowledge domains, namely technological knowledge, pedagogical knowledge, and content knowledge (Koehler & Mishra, 2009). In science education, TPACK refers to integrating pedagogy and technology knowledge into science content knowledge (Lin et al, 2013). The TPACK framework includes 7 dimensions explained as follows: Technological knowledge (TK): General knowledge about technology. This could include knowledge about climate change technologies for instance. Pedagogical knowledge (PK): General knowledge about learning and teaching. Content knowledge (CK): Knowledge about subject matter. Pedagogical content knowledge (PCK): Pedagogical knowledge that teachers should have to teach the subject matter. Technological content knowledge (TCK): Technological knowledge that teachers should have to teach the subject matter. Technological Pedagogical Content Knowledge (TPACK): Knowledge about the integration of a specific subject matter with technological and pedagogical knowledge.

Cognitive structures are also important in determining one's understanding of a subject, and they can be defined as patterns of relationship between related concepts (Kempa & Nicholls, 1983). Word association tests (Özatlı & Bahar, 2010; Kaya & Akış, 2015) can help identify meaningful connections between concepts and misconceptions, alongside other visual techniques like concept maps, flow maps, and diagrams. It can also be used to help design educational interventions and evaluate their effectiveness (Bahar, Johnstone, & Sutchliffe, 1999), indicating conceptual change (Duit & Treagust, 2003). Word association tests were used to determine teachers' cognitive structures regarding climate change (Daskolia et al., 2006; Cebesoy & Karisan, 2022). However, research has been limited in identifying faculty members' TPACK and cognitive structures following a climate change professional development workshop. The goal of this study was to investigate faculty members' TPACK self-efficacy perceptions and cognitive structures after attending a professional development workshop.

RESEARCH METHOD

TECCHED Curriculum & e-books & Digital Learning Platform

The TECCHED consortium (i.e., consisting of universities from Türkiye, Bulgaria, Latvia, Lithuania, a small-medium enterprise from Spain and an organization from Belgium) created a technology enhanced climate change curriculum based on a literature review and expert panels conducted in partner countries. The curriculum consisted of 4 competence domains: (a) Content knowledge, (b) Causes of change, (c) Effects of change, (d) Mitigation and adaptation. Each competence domain is divided into topics related to climate change topics. For each topic, character and value domains to be developed, along with specific learning objectives, are clearly defined. Each topic is presented in the format of an enriched book. These books include introductory information with general explanations, additional resources, and interactive materials related to the topic. They also contain lesson plans designed according to the widely used 5E instructional models, which is a well-known and widely used instructional method in science teaching. The enriched books are accessible through the digital learning platform available on the ***tecched.eu*** website. Thanks to this platform, each lesson plan incorporates one or more technologies to be used in teacher training for teaching climate change. The platform also includes a technology catalogue and specially designed assessment tools for each book.

TECCHED Workshop

A total of 24 faculty members from Turkey, Bulgaria, Lithuania, and Latvia participated in the three-day faculty training event in Latvia. During this workshop, they learned about the TECCHED project and its objectives, as well as how to use the digital learning platform and effectively implement the curriculum. As a result, faculty members were trained to use the eBooks' content to gain curricular experience. The participating faculty members were expected to use the TECCHED tools in their university classrooms.

Research Design and Questions

A one group pre-test-post-test design was utilized to identify the changes after faculty members participated in the workshop (Bernard, 2013). To understand the effectiveness of the workshop and the implementation of TECCHED curriculum on faculty members the following research questions were asked.

(1) What is the effect of a professional development workshop on climate change on faculty members TPACK self-efficacy perceptions?

(2) How do faculty members' cognitive structures about climate change education change after attending the professional development workshop?

Participants

A total of 24 faculty members received training during the three-day professional development workshop in Latvia. Of these, 17 faculty members voluntarily completed the TPACK self-efficacy perception test, which was administered before and after the training, and 13 faculty members voluntarily took the Word Association Test.

Data Collection Tool

Two different data collection tools were used in this study:

TPACK self-efficacy perception scale: As TECCHED aims to enhance faculty members' TPACK competencies, the TPACK Self-Efficacy Perception Scale developed by Kiray (2016) was employed. The scale is a self-report, 5-point Likert scale (1 = not knowledgeable at all, 5 = very knowledgeable), consisting of 55 items. The original reliability coefficients for the scale and its sub-dimensions are as follows: CK (0.866), PK (0.902), TK (0.875), TCK (0.916), PCK (0.792), TPK (0.922), and TPACK (0.924). The reliability coefficient for the overall scale is 0.969.

Word Association Test: In the Word Association Test stimulus words are given to the participants and they are asked to write associated words within a given time (Bahar & Hansell, 2000). In this regard, the "Climate

Change Education" and "Climate Change" were given as a stimulus word. Participants were given 30 seconds and asked to write associated words.

Data Analysis

The Shapiro-Wilk test was used to determine the normality of faculty members' pre-test and post-test scores in terms of technological pedagogical content knowledge self-efficacy perceptions. The Wilcoxon signed-rank test was used to compare pre-test and post-test scores due to the data's non-normal distribution. While determining Cognitive Structures about Climate Change and Climate Change Education of Faculty Members, the responses collected from participants were analyzed using the content analysis technique. The goal was to allow for a comparison of knowledge structures before and after training.

FINDINGS

TPACK Self Efficacy Perceptions

The normality of the pre-test and post-test scores was calculated using the Shapiro-Wilk test. The results revealed that the distribution of both pre-test (W = 0.906, p<0.001) and post-test (W=0.846, p<0.001) scores significantly deviated from normality, as indicated by p-values below the 0.05 threshold. This finding suggests that the assumption of normality is violated for both datasets.

The Wilcoxon signed-rank test was used to compare pre-test and post-test scores due to the non-normal distribution of the data, which was evident by the Shapiro-Wilk test results. The analysis revealed a statistically significant difference between the two sets of scores (W=15021.0, p<0.001), suggesting that the intervention had a measurable impact on participants' self-efficacy. This result indicated that the intervention was effective in enhancing participants' TPACK self-efficacy perceptions.

Word Association Test: The results indicated that for the term "climate change education" there were 63 distinct words in the post-test while there were 59 in the pretest. Due to the small number of participants. Three most repeated responses were given for each stimulus word (Table 1).

Table 1. Most repeated words for "Climate Change Education"

	Pre implementation			**Post implementation**		
	1	**2**	**3**	**1**	**2**	**3**
Climate change	Global warming	Pollution, Deforestation, Carbon emissions	Melting glaciers, rising sea levels, biodiversity loss, extreme weather	Global warming, climate, greenhouse gasses, biodiversity loss, deforestation	Rising, temperatures, carbon footprint, climate science, youth engagement etc.	Biodiversity loss
Climate change education	Awareness	Renewable energy	Sustainability	Sustainability	Climate scenarios	Renewable energy, Adaptation, Mitigation, Environmental responsibility, resilience

For the term climate change education there was a shift in focus in the participants' responses. Pretest heavily emphasized the general awareness and technical words. There was a strong focus on technical and knowledge-based skills. However, in the post-test, Broader and more holistic themes, such as global citizenship, resilience building, and community action were repeated, a focus on mitigation and adaptation strategies, alongside policy measures, was present. The inclusion of values and character development as part of education, indicating a more socio-emotional approach to teaching climate change was shown.

Considering the content of the responses, in terms of educational methods pre-test responses were more inclined towards knowledge-driven approaches, while post-test responses included more action-oriented approaches. The educational methods mentioned in the post-test included more interactive and digital approaches than the pretest responses. In terms of character and values, those were rarely mentioned in the pretest but were more emphasized in the post-test. There was a broader focus on policy measures in the post-test responses. Post-test responses reflect innovative, more active educational strategies (Table 2).

Table 2. Content analysis results for "Climate Change Education" stimulus

Aspect	Pre-test	Post-test
Approach	Knowledge-driven: focuses on awareness, literacy, and technical data (e.g., statistical data, climate science)	Action-oriented: highlights advocacy, resilience, and values-based education
Educational Methods	Content knowledge, statistical data, project design, movies, and SDGs	Interactive learning, hands-on learning, interdisciplinary approaches, and digital platforms
Focus on Skills	Technical skills: competences in data analysis and using models	Broader skills: critical thinking, global responsibility, and advocacy skills
Values and Character	Implicit, minimally mentioned	Explicit, emphasized as core educational components
Action and Policy	Limited to project designs and technical strategies	Broader focus on policy measures, green practices, and community involvement

Overall, the results showed that from the pre-test to the post-test faculty members were more focused on taking action instead of focusing on solely teaching the content knowledge related to climate change. Their responses also included more use of character and values dimensions such as responsibility, empathy, resilience and the results included more moral reasoning aspects. Finally, the results also highlighted that the faculty members were more aware of the broader themes like global citizenship, advocacy, and interdisciplinary education.

For the word climate change, pretest results indicated that the participants linked the word with the consequences of climate change more specifically on global warming and extreme weather events. There was also a strong emphasis on the climate-specific terminology used in the pre-test responses. Several responses indicated a sense of urgency, reflecting the understanding of climate change as an immediate and critical issue. Some responses in the pretest also indicated a sense of urgency, including crisis, emergency and disaster words. Post-test results, on the other hand, indicated a continued association of climate change with environmental impacts but the word ecosystem appeared more in the responses, which may be interpreted as the increased awareness of the interconnectedness of ecosystems. The scope of climate change expanded and included responses for broader social and ethical aspects of climate change. This also might indicate that the participants reflected their understanding about the moral and ethical aspects of the issue. In the post-test responses, there was an increase in action-orientated responses. Words like "action" and "advocacy" suggest a shift from merely recognizing the problem to actively considering the steps needed to address it. The post-test results also showed an increased focus on personal and collective responsibility.

DISCUSSION AND CONCLUSION

The results revealed that the professional development workshop significantly enhanced the TPACK self-efficacy perceptions of participating faculty members. The statistical results showed that the faculty training was effective in increasing faculty members TPACK self-efficacy perceptions. The result highlights the significance of targeted professional development programs in fostering faculty members competencies in teaching climate change.

The comparison of pre-post responses of faculty members to the word “climate change” indicates participants’ knowledge structures and understanding towards the phenomena. Although the initial responses were focused on scientific and environmental aspects, post-test responses revealed a broader and more nuanced conceptualization, adding ethical responsibility, social solidarity, and the interconnectedness of environmental and human systems in the knowledge structure. In the post-test action-orientated themes and responsibility became prevalent. The comparison of pre-test and post-test responses to the stimulus word "climate change education" has also demonstrated a shift in participants’ understanding from a traditional, knowledge-focused view to an integrated values-driven and action-orientated perspective. In the pre-test responses, knowledge acquisition and raising awareness were more focused. In the post-test responses, however, the importance of character and values, fostering values, activities and teaching methods were emphasized. The evolution in responses indicates the effectiveness of character and values education in deepening participants' different perspectives. They understood climate change education as not merely an academic approach but a transformative process that prepares individuals to take informed, responsible, and proactive roles in addressing climate change. Therefore, TECCHED was effective in bringing ethical and knowledge domains together.

Overall, based on the results of the faculty training as well as the implementation of the TECCHED training with preservice teachers it could inform the field of climate change education as follows:

1. The improvement in TPACK self-efficacy perceptions highlights the importance of direct and structured professional development. Higher education institutions can implement professional development about complex issues such as climate change as continuous learning opportunities for faculty members. Institutions can establish ongoing workshops or communities of practice to reinforce and expand faculty members' TPACK development over time.
2. Word association tests can serve as a diagnostic tool to track changes in faculty members’ cognitive structures after TECCHED training and implementation. Based on the results, professional development could be adjusted based on the faculty members’ needs. This approach could also be

expanded to compare cognitive structures across disciplines so that the training content can be altered based on the needs of the faculty members.

Results revealed that faculty members' perspectives change from theoretical concepts to more practical strategies. This demonstrates that the TECCHED professional development workshop had a transformative impact on faculty members. Therefore, professional development programs should focus more on practice-orientated training so that the faculty members enhance their ability to bring about change in their classrooms. Furthermore, future studies could focus on the in-class implementation of faculty members' climate change education and investigate the impact of such training on preservice teachers' TPACK self-efficacy perceptions as well as their cognitive structures.

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Implementing Sustainability in Textile Engineering Through Service Learning: A Case Study of the Sustainable Knitting Lab

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ABSTRACT

This study examines the implementation of service learning to integrate sustainability education into textile engineering curricula. Developed within the Erasmus+ TexUnite project framework, Ege University's Sustainable Knitting Lab engaged students in a comprehensive service-learning experience that combined theoretical knowledge of sustainable textile practices with hands-on production and community engagement. The project involved 17 students who participated in educational workshops on EU regulations for recycled materials, produced knitted scarves and gloves using recycled yarns, engaged in virtual international exchanges with Hochschule Albstadt-Sigmaringen (Germany), and contributed to community service through collaboration with +1 Down Kafe, a social enterprise employing individuals with Down syndrome. Pre- and post-assessment evaluations demonstrated significant improvements in students' sustainability awareness, environmental consciousness, and readiness to engage in sustainable practices. The project culminated in a public exhibition at Ege University Science Festival 2025, highlighting both student learning outcomes and community impact. Results indicate that service learning provides an effective pedagogical framework for developing sustainability competencies while fostering civic engagement and cross-cultural collaboration in textile engineering education.

Keywords: *Sustainability, service learning, textile engineering, virtual exchange, open educational resources (OER)*

INTRODUCTION

The global textile and fashion industry faces unprecedented sustainability challenges that have positioned it among the most environmentally damaging sectors worldwide. Accounting for an estimated 10% of global carbon emissions and contributing to approximately 20% of industrial water pollution, the industry generates more than 92 million tons of waste annually while perpetuating a linear "take–make–dispose" production model that accelerates resource depletion and environmental degradation (Niinimäki et al., 2020; Cobb, Keough, Cao, Shaffer, & Jelenewicz, 2020). Beyond environmental concerns, the sector is associated with persistent social issues, including exploitative labour practices, unsafe working conditions, and inadequate wages throughout global supply chains, disproportionately affecting vulnerable communities in developing countries (Fletcher & Tham, 2019). The rise of fast fashion has intensified these issues by fostering overconsumption, short product lifecycles, and a culture that prioritizes speed and low cost over environmental stewardship and social responsibility.

Given the magnitude and complexity of these challenges, a fundamental transformation in textile engineering education is urgently needed to prepare future professionals who can navigate and address multifaceted sustainability issues. Traditional textile curricula have historically emphasized technical proficiency, production efficiency, and design innovation, while giving limited attention to the environmental and social consequences of textile production (Gwilt, 2020). However, the contemporary textile sector requires graduates equipped not only with technical expertise but also with sustainability literacy, systems-thinking capabilities, and ethical decision-making skills (Armstrong & LeHew, 2011). This transformation cannot be achieved through superficial additions of sustainability topics to existing curricula. Instead, it requires pedagogical approaches that integrate sustainability at the core of learning, fostering critical reflection on the industry's role within broader ecological and social systems (Lozano, Merrill, Sammalisto, Ceulemans, & Lozano, 2017).

Service Learning (SL) emerges as a particularly effective pedagogical strategy for realizing this integration. Defined as "a form of experiential education in which students engage in activities that address human and community needs together with structured opportunities designed to promote student learning and development" (Jacoby, 2015), SL combines academic rigor with meaningful community engagement. By situating learning in authentic contexts, SL enables students to apply theoretical knowledge to real-world problems, cultivate civic responsibility, and strengthen professional competencies (Eyler & Giles, 1999). In textile education, SL offers unique opportunities for students to engage directly with sustainability challenges through hands-on projects that address real community needs like ranging from upcycling programs and textile waste audits to the creation of educational resources promoting sustainable consumption practices (Masina, 2024; Sehnem et al., 2023; Wood et al., 2022; Rotimi et al., 2021).

Previous research demonstrates that SL enhances student engagement, improves academic outcomes, and increases motivation for lifelong learning while simultaneously addressing community needs (Celio et al., 2011). Within sustainability education, SL empowers students to witness the tangible impact of their work, develop empathy for diverse stakeholders, and appreciate the interconnected nature of environmental and social challenges (Sterling, 2004). Furthermore, SL often fosters interdisciplinary collaboration, connecting textile-engineering students with environmental sciences, social work, and community development, while also enabling international collaboration through virtual exchanges with partner institutions (Gerstenblatt & Gilbert, 2014).

Against this backdrop, this paper presents the Sustainable Knitting Lab at Ege University as a case study demonstrating the effective application of SL in textile sustainability education. Developed within the framework of the Erasmus+ TexUnite – Service Learning on Sustainability in Textile and Fashion Education project, the Sustainable Knitting Lab integrated theoretical learning on sustainable practices with hands-on production using recycled yarns, intercultural collaboration through virtual exchange, and community engagement through cooperation with Down Café, a social enterprise employing individuals with Down syndrome. By documenting the project's methodology, implementation, learning outcomes, and community impact, this paper seeks to provide a replicable model for integrating SL approaches into sustainability-focused textile curricula.

Service Learning as Pedagogy

Service Learning (SL) has gained increasing recognition as a transformative pedagogical approach that bridges academic study with real-world application. It combines structured learning outcomes with active community engagement, offering students opportunities to apply disciplinary knowledge while addressing societal needs. Unlike traditional coursework, which often remains confined to classroom instruction, SL situates learning in authentic contexts that demand problem-solving, ethical judgment, and collaboration (Jacoby, 2014).

In higher education, SL is particularly valued for its ability to enhance student engagement and deepen understanding of complex issues. Research has consistently demonstrated that SL fosters improved academic achievement, critical thinking, and reflective practice, while also nurturing civic responsibility and social awareness (Eyler & Giles, 1999; Celio et al., 2011). The model requires students to confront real-world challenges, reflect on their experiences, and connect these with theoretical frameworks, thereby strengthening both cognitive and affective learning outcomes.

Applied to textile and fashion education, SL creates unique possibilities for integrating sustainability into curricula. Students not only study the technical and environmental dimensions of textile production but also witness first-hand its social implications. Through community-oriented projects such as textile waste reduction initiatives, upcycling workshops, or collaborative product development with social enterprises, students gain practical experience in addressing sustainability challenges. These experiences build empathy, cultivate ethical awareness, and encourage active citizenship, complementing technical skill development with broader social competencies.

SL also promotes interdisciplinary and intercultural learning, both of which are essential in addressing the multifaceted nature of sustainability. Textile engineering students often collaborate with peers from environmental sciences, social sciences, or business disciplines, broadening their perspectives and learning to navigate diverse viewpoints. At the same time, SL projects conducted within international partnerships encourage intercultural exchange and comparative reflection. Initiatives such as virtual exchanges expand this potential by enabling students to collaborate across borders, share experiences, and develop global perspectives on sustainability.

In summary, SL represents a pedagogical model that aligns particularly well with the goals of sustainability education. By uniting technical knowledge, social responsibility, and experiential learning, SL prepares textile-engineering students not only to become proficient professionals but also to act as agents of change within an industry facing urgent environmental and social challenges.

Project Context: TexUnite and SusTexLab

The *TexUnite – Service Learning on Sustainability in Textile and Fashion Education* project was launched under the Erasmus+ programme to promote sustainability competencies in textile and fashion education. Coordinated by the University of Education Freiburg, it unites six partner institutions, including Ege University, around a shared mission: integrating sustainability through Service Learning (SL), Virtual Exchange (VE), and Open Educational Resources (OER).

A central pillar of the project is the Sustainable Textile Laboratory (SusTexLab), which provides thematic seminars on sustainability models, EU regulations, service learning methodology, and virtual exchange. These sessions serve as a pedagogical foundation, enabling each partner to design sustainability-oriented SL projects that apply classroom knowledge in real-world contexts.

At Ege University, three SL projects were planned within this framework. This paper focuses on one of them: the Sustainable Knitting Lab, which serves as a case study demonstrating how service learning can be implemented to connect technical textile education with sustainability and community engagement.

Case Study: The Sustainable Knitting Lab at Ege University

The Sustainable Knitting Lab was developed at Ege University's Department of Textile Engineering as a flagship service-learning project under TexUnite. Its central goal was to connect sustainability education with hands-on textile practice and social responsibility.

Objectives

- Integrate sustainability concepts into technical training.
- Provide students with practical experience using recycled yarns (r-PET and cotton).
- Encourage reflection on environmental and social implications of textile production.
- Engage with the community by presenting and sharing project results at public events.

Activities

Students participated in seminars on recycling, circular economy, and sustainable yarns before beginning practical training on flat and glove knitting machines. Working in groups, they produced knitted scarves and gloves, confronting real technical challenges such as yarn irregularities and spirality in fabrics. These experiences required adjustments in machine settings and strengthened their problem-solving capacity.

Alongside production, students prepared OER materials, including worksheets and posters, documenting both the technical processes and the sustainability reflections. These outputs will be later used for dissemination through the ZOERR and EPALE repositories.

Community and Public Engagement

The project emphasized interaction with society. A community event was organized at the +1 Down Kafe, where students met individuals with Down syndrome, shared information on sustainability, and gifted the knitted products. Additionally, the project was showcased at the Ege Science Festival (May 2025), where students presented their outcomes to a wider public, strengthening awareness of sustainable textiles among other students and visitors.

Pedagogical Value

The Sustainable Knitting Lab showed how technical training, awareness of sustainability, and community involvement can come together in one project. Students improved their technical and teamwork skills while gaining confidence in talking about sustainability to different audiences. By connecting classroom work with community events and public presentations, the project became a strong example of service learning in textile engineering.

METHODOLOGY

The Sustainable Knitting Lab was designed as a service learning project combining classroom instruction, laboratory practice, community engagement, and structured evaluation. To measure and document its impact, three complementary methodological tools were applied: pre- and post-tests, virtual exchange, and open educational resources (OER) development.

Pre- and Post-Tests

Students at Ege University completed online surveys before and after the project. The surveys measured their attitudes toward sustainability, their willingness to take action, and their perceptions of the educational value of virtual exchange. Questions were structured using Likert scales and included both closed and open items. This approach allowed for a comparison of students' sustainability awareness and engagement before the intervention and after the service-learning experience.

Virtual Exchange

The project included a series of virtual exchange (VE) sessions with partner universities. These were conducted in English and offered students opportunities to present their work, discuss sustainability topics, and exchange cultural perspectives. The VE activities served multiple purposes: improving digital literacy, strengthening intercultural communication, and broadening the context of sustainability learning beyond national boundaries.

OER Development

All teaching materials and project outputs were documented and converted into open educational resources (OER). These included lesson plans, worksheets and posters produced by students and teachers. Materials were prepared according to Creative Commons licensing guidelines and will be uploaded to the ZOERR repository in Baden-Württemberg and the EPALE platform at the European level. This ensured that the results of the project would remain accessible to other educators, students, and stakeholders in textile and fashion education.

Together, these methodological components enabled both the assessment of learning outcomes and the long-term dissemination of the project's educational value.

FINDINGS

The Sustainable Knitting Lab involved 17 students from the Department of Textile Engineering at Ege University who completed both pre- and post-tests. The results show clear improvements in sustainability awareness, willingness to act, and the perceived value of international collaboration.

Attitudes toward Sustainability

Post-test data revealed a strong increase in students' preference for eco-fair textile products, their willingness to donate or reuse clothing, and their habit of checking sustainability labels when shopping. Neutral responses that had been common in the pre-test were nearly eliminated in the post-test, suggesting that students had developed more decisive and committed attitudes after the project.

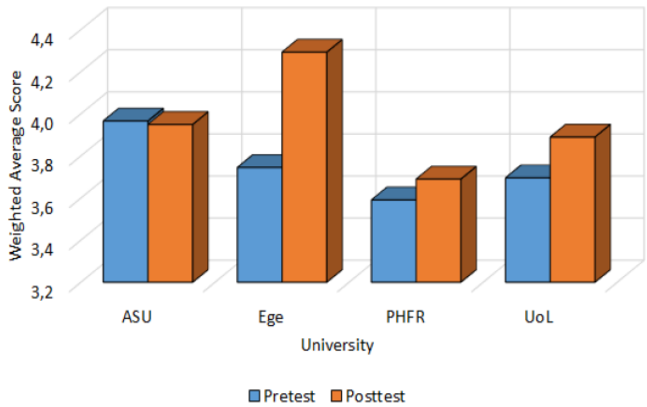

Figure 1. Weighted Average Score for Personal Attitudes

Potential for Action

Students also expressed a stronger belief in their own capacity to act sustainably. Post-test answers indicated greater agreement on the importance of passing on clothing, taking social responsibility, supporting circular economy principles, and cooperating with sustainability-oriented stakeholders. Again, neutral positions decreased, pointing to a consolidation of students' readiness to act in line with sustainability goals.

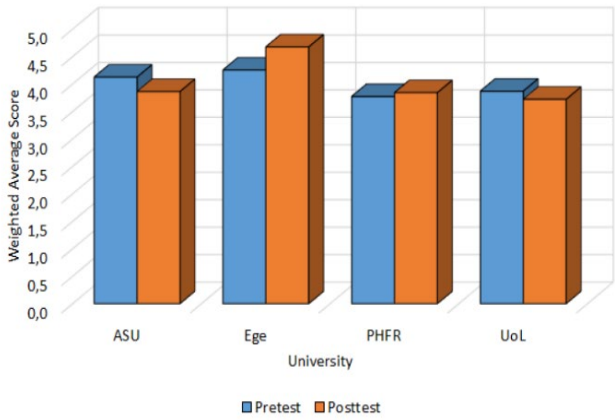

Figure 2. Weighted Average Score for Potential for Action

Educational Value of Virtual Exchange

Ege students showed particularly positive responses regarding the Virtual Exchange component. In the post-test, almost all students expressed strong agreement that VE was valuable for exchanging ideas with peers abroad, expanding intercultural knowledge, and reinforcing sustainability awareness. Negative and neutral responses were virtually absent.

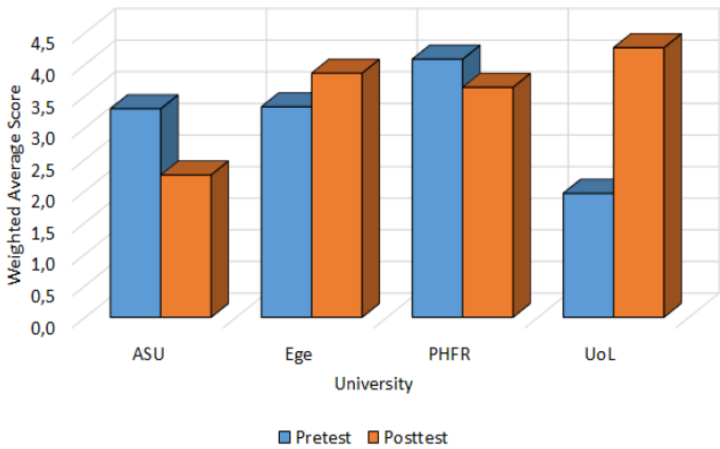

Figure 3. Weighted Average Score for Educational Potential through Virtual Exchange

Comparative Observations

When compared with results from other partner universities, Ege University students demonstrated the most consistent growth across all three areas: attitudes, potential for action, and perceptions of virtual exchange. This suggests that the hands-on character of the Sustainable Knitting Lab, combined with its strong community engagement, contributed to particularly robust outcomes.

Table 1. Comparative observations

University	Attitudes Toward Sustainability	Potential for Action	Educational Value of VE
ASU	↑ Stronger support for sustainable textiles and greenwashing awareness; ↓ belief in personal responsibility	↓Slight decline in strong agreement; selective gains in cooperation and waste minimization	↓Decline in strong agreement; tempered enthusiasm
Ege	↑ Clear shift toward eco-fair products, donations, label-checking; ↓ neutral views	↑Consistent gains across all items; strong consolidation of positive views	↑Increase in strong agreement across all VE items
PHFR	↑ Positive changes in second-hand shopping and climate awareness; cost concerns persist	Moderate gains; cautious endorsement of cooperation and waste minimization	↓Decline in strong agreement; shift to moderate views
UoL	↑ Support for eco-fair products, donations, labels; ↓ slight drop in strong agreement	Small improvements: neutrality remains high	↑Substantial increase in strong agreement across all VE items

Arrows indicate direction of post-test changes relative to pre-test.

DISCUSSION

The findings of the Sustainable Knitting Lab show that service learning can be an effective way to integrate sustainability into textile engineering education. Students at Ege University developed stronger views about sustainable consumption, became more confident in their ability to act, and valued the opportunities created through international collaboration. Several aspects of the project help explain these results.

One important factor was the practical work in the laboratory. Students used recycled PET and cotton yarns on knitting machines and faced concrete difficulties such as yarn irregularities and spirality. Solving these problems required them to adjust technical settings and apply their engineering knowledge in real situations. In this way, sustainability was experienced not as a theory but as a challenge connected to materials and processes.

Another factor was the interaction with the public. Students presented their work at the +1 Down Café and the Ege Science Festival, which allowed them to communicate their results to different audiences and to feel that their work had meaning outside the university. These experiences helped students connect their technical work with social responsibility.

A further element was the documentation of project outcomes. Students produced worksheets and posters that will later be published as Open Educational Resources (OER) on platforms such as ZOERR and EPALE. The upload process has not yet been completed; it will follow once all service-learning projects in the consortium are finished. Nevertheless, the preparation of these materials encouraged students to structure their knowledge in ways that are useful for others.

When looking at results across all partner universities, Ege University showed the most stable improvement. This can be linked to the way the project combined technical tasks, public engagement, and structured reflection. At the same time, some limitations need to be acknowledged. The recycled yarns created extra technical problems, which extended the production process, and the relatively small number of participants (17 students) restricts the scope of generalisation.

Overall, the Sustainable Knitting Lab demonstrates that linking classroom learning with practical application and community contact can create meaningful educational outcomes. It suggests that service learning is a valuable approach for preparing textile engineers to address sustainability challenges in their future careers.

CONCLUSION

The Sustainable Knitting Lab at Ege University illustrates how service learning can be used to bring sustainability into textile engineering education in a concrete and meaningful way. By working with recycled yarns, students linked technical knowledge with environmental concerns and experienced first-hand the challenges of sustainable production. Through public activities such as the Down Café event and the Ege Science Festival, they also connected their academic work with society and developed a stronger sense of responsibility.

The project results, measured through pre- and post-tests, show that students gained clearer attitudes toward sustainability, a stronger willingness to act, and greater appreciation for intercultural exchange. These findings suggest that service learning can be an effective method for building the competencies needed in the textile and fashion sector to respond to global sustainability challenges.

Future work will focus on expanding the number of participants, improving the integration of international collaboration, and finalising the publication of open educational resources (OER) so that the results can be shared with wider audiences. The Sustainable Knitting Lab can serve as a replicable model for other institutions seeking to combine technical training with sustainability and community engagement in engineering education.

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Evaluation of the Need for Digital Twin Technology in Civil Engineering for Climate Resilience

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ABSTRACT

Digital Twin (DT) technology can profoundly change civil engineering applications, including the monitoring, simulation, and management of infrastructures. Especially as climate change accelerates, it is essential for engineers to integrate DT capabilities into their education and practice as an innovative way to enhance resilience against extreme events. This study assesses the need for integrating DT into civil engineering curricula, mainly for improved climate resilience. A mixed-mode questionnaire was administered to 53 participants in Turkey, Portugal, and Spain, including higher-education students, early-career professionals, and stakeholders. Respondents were asked about their awareness, use, and training in DT technology, as well as their exposure to climate-resilience guidelines; participants represented a balanced mix of students, young professionals, and stakeholders from both European and non-European backgrounds. The findings reveal a significant gap between conceptual awareness of DT and its practical adoption, particularly in climate-resilience applications. By summarizing the responses regarding perceptions and training needs, this paper highlights the necessity of embedding DT technology and climate-resilience considerations into civil engineering education.

Keywords: *Digital twin, climate resilience, need analysis, civil engineering.*

INTRODUCTION

Digital twin (DT) technology has become one of the most prominent technologies nowadays, considering it can be used for monitoring, analysing, and to improve a system in real time by benefitting data from a physical object (sensors), process, or system (Iliuta et al., 2024; Zhang et al., 2024). With advances in data collection and the computing ability of devices, DT have started to be used in many sectors to improve efficiency, sustainability, and security. DT are systems that help organizations predict potential problems and thus allow decision makers to observe the situation based on data (Iliuta et al., 2024; Zhang et al., 2024). Similar to other sectors, digital twin could also be transformative technology for civil engineering as well. It can provide an innovative approach at every stage of construction, including design, building, and monitoring, especially for fundamental structures such as bridges, dams, roads, and buildings. By combining sensor data and digital models, DT can provide a better understanding of how infrastructure components behave over time compared to traditional inspection methods, supporting more reliable, scalable, and sustainable systems (Petri et al., 2023; Tan & Li, 2024; Callcut et al., 2021).

On the other hand, climate change has been intensifying and producing negative impacts on the world's ecosystems, economies and societies. In addition to being threaten to society, rising average temperatures, increasing frequency of heat waves, storms and floods, sea level rise has been a challenge for engineers and infrastructures (Zhang et al., 2022; Stewart et al., 2011). Within this context, these climatic changes have been caused to higher thermal loads, accelerated corrosion, greater wind pressures and more severe precipitation on buildings, bridges, roads and water systems. Traditional design methods that is taken stationary climate conditions into account needs to be reconsidered to ensure safety, sustainability and durability of a structure. Digital twin technology could provide an innovative approach to overcome these challenges by collecting sensor data from the systems, creating a digital model to monitor and simulate infrastructure performance under changing climatic conditions and are increasingly applied in resilience cases such as flood forecasting, for monitoring coastal erosion, and heatwave impact analysis, testing new strategies before real world applications. In addition to this, other urban systems like mobility, energy, and water networks, digital twins could provide a systemic approach to climate resilience. Moreover, DT could support lifecycle management by helping infrastructure planners (Zhu & Jin, 2025).

In recent years, various studies in the civil and engineering fields have focused on using digital twins to evaluate and monitor the effects of climate resilience. For example, the wind energy potential of high-rise buildings in Makati was evaluated by using DT technology to monitor wind patterns that could be employed as a supplemental energy source (Ballinan et al., 2024). Iconic structures such as the Sydney Opera House have also been monitored continuously with DT systems where creep and shrinkage data collected for maintenance planning under changing climate conditions (Tahmasebinia et al., 2019). Other studies have applied DT to optimize ventilation and humidity control in sensitive underground heritage sites (Zhang et al., 2022). In construction safety are, DT is applied to build an early warning systems to monitor possible tunnel collapse risks and improve worker protection during risky events (Ye et al., 2023). There are some works where DT frameworks including integrating building information modelling (BIM), geographic information systems (GIS), and internet of things (IoT) have also been applied to construction processes to limit ineffectiveness and reducing emissions or used scan-to-FEM approaches to assess and mitigate foundation-induced damage in historical buildings (Lee & Lee, 2021; Funari et al., 2021). Another study developed a simulation by means of DT for a masonry building integrating experimental and numerical data to monitor structural health and long-term deterioration under the loads (Angjeliu et al., 2020). A recent case study on built data links between a construction site and its digital twin showed how sensor data and images can be sent to a dashboard and used to make better decisions during construction. The study also indicates that using DT in real projects can improve safety and efficiency but still faces some challenges (Chacón et al., 2024). The all reviewed studies showed that DT technology is evolving from conceptual models to practical tools for predictive maintenance systems especially for special buildings.

The literature study indicates the gap between the technical possibilities of digital twins and their adoption in civil engineering applications. Therefore, this study was conducted to investigate the need for increasing awareness and practical adoption of digital twins by integrating them into civil engineering curricula, preparing guidelines and documentation, to promote increased benefit from DT technology through targeted educational materials. In this context, a fundamental needs analysis was performed to evaluate the current level of DT awareness, how they use it, training needs in young, future professionals and stakeholders.

RESEARCH METHOD

Research Model

A need analysis was conducted with a mixed mode survey consisting of one open ended and fifteen closed ended questions. The survey was aimed to evaluate the awareness and knowledge of DT technology in future and young professionals in civil engineering, and also to identify their needs for curricula, resources, and guidelines for DT. This approach was chosen to obtain both quantitative and qualitative data, enabling the determine of the gap in DT knowledge and possible training, resources and guidelines. The questionnaire consisted of 16 items (15 closed-ended and 1 open-ended). Closed-ended questions were a five point Likert scale to evaluate the awareness, usage, and training needs, while the open-ended question was aimed to collect additional qualitative suggestions. The participation was totally anonymous, and no personal identifiers were collected. The questionnaire and its procedures were reviewed and approved by the Ethics Committee of Ege University prior to data collection.

Participants

The questionnaire was applied in Turkey, Portugal and Spain. Three main groups in civil engineering was targeted; a) Future professionals: higher education (HE) programs, trainees in vocational education and training (VET) students in civil engineering and construction programs. b) Young professionals: graduated within 5 years and has work experience in civil engineering or related fields. c) Stakeholders: Educators, researchers and construction experts in fields.

A total of 53 valid responses were received: 56 % from EU countries and 44 % from non-EU countries (Fig. 1).

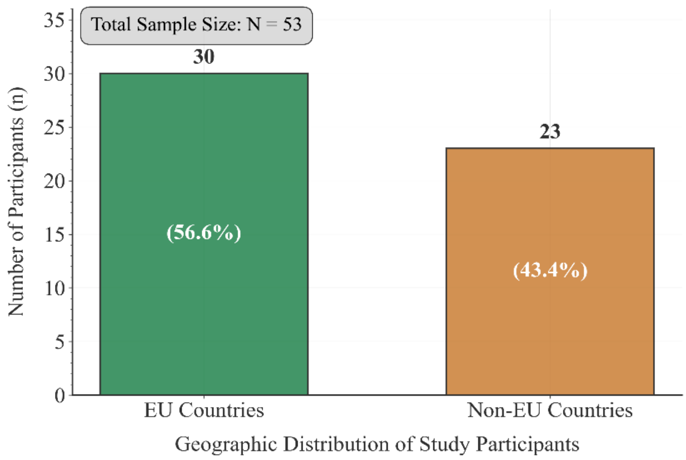

Figure 1. Distribution of study participants

The three target groups were almost equally represented: future professionals (18 participants), young professionals (17) and stakeholders (18) (Fig. 2). This balanced distribution allowed comparisons throughout every career stages.

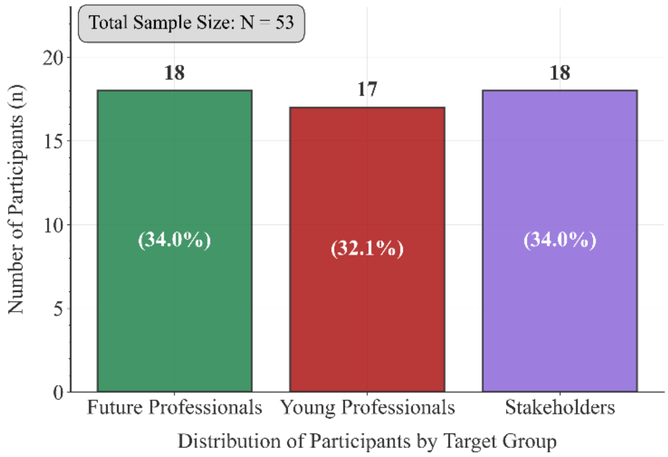

Figure 2. Distribution of participants by target group

Data Collection Tool

Respondents were asked about their awareness and use of digital twin tools, if they had ever attended training and had used a DT tool for climate-resilience applications. They were also questioned about the perceived usefulness of learning resources and their need for guidance for DT. In addition, an open-ended question was included to obtain feedback and suggestions from respondents.

Collection of Data

The survey was studied and data gathered from participants during in spring 2025. The questionary was distributed by means of invitations from consortium partners in Turkey (EGE), Portugal (ENTER) and Spain (O&B, EOLAS). The need analysis was performed both online and in face-to-face sections. During data processing phase, the responses were collated anonymously.

Data Analysis

For proportions, Wilson 95 % confidence intervals were computed to provide some intervals for data.

FINDINGS

Awareness, Use and Training

Most respondents were found that they were familiar with DT technology, as 74 % (39/53) of participants indicated that they aware of it, yet only of 38 % (20/53) them had used a digital-twin tool in practice. Even fewer participant (26 %) had attended a training course or workshop (14/53). Fig. 3 summarizes awareness, use and training attendance. These results suggest there is a gap between awareness and practical experience might emphasize the importance of opportunities of practical trainings. Nearly half of the respondents also stated that they never analysing wind, thermal, or other climate related calculations in their work.

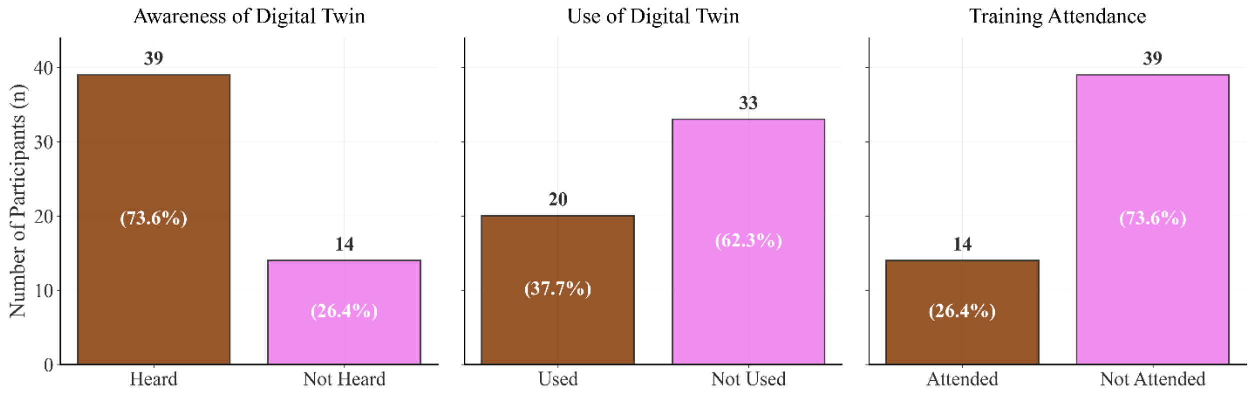

Figure 3. Awareness, use and training attendance on digital-twin technology

Climate-Resilience Guidance and Training

Only 7.5 % of participants (4 out of 53) have accessed any guidelines on using DT applications for climate resilience, while 92.5 % of responded have not. The stats were getting lower for training, as just one person (1.9 %) have attended a training program, and the rest have not (Fig. 4). These findings show that most respondents have almost no interactions to guidance or training for how to use DT technology for climate resilience purposes in engineering sector.

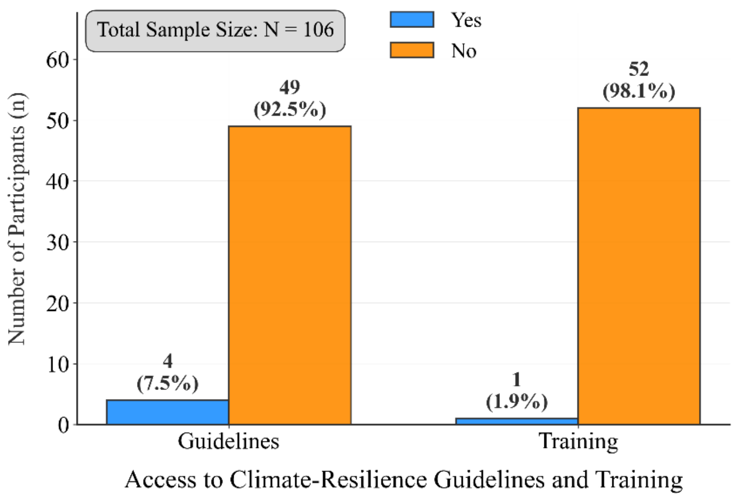

Figure 4. Access to climate-resilience guidelines and training program

Perceived Usefulness of Learning Resources

Respondents were also asked how they find it useful various learning resources about DT technology. The findings were represented as a bar chart in Fig. 5. A possible access to case studies showing the application of DT in construction and engineering was considered useful by 77 % of participants, whereas 19 % found it as neutral, and only 4 % thought that the resources on DT would not be useful. Basic learning materials were found useful by 83 %, and not useful by only 4 %. Finally, 81 % of participant stated that guides and resources integrated into HE and VET curriculum would be beneficial.

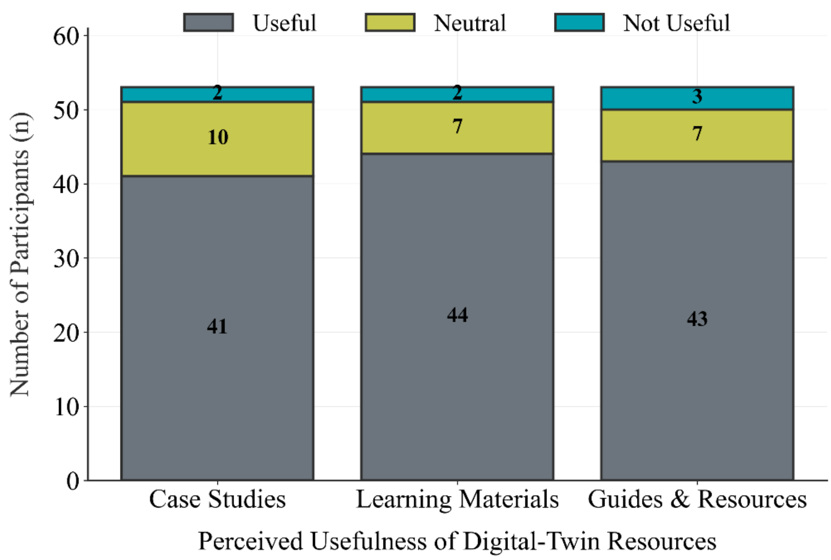

Figure 5. Perceived usefulness of case studies, learning materials and guides for DT

Statistical Analysis

The data collected from respondents were analysed by means of basic statistics, as CI (Confidence Interval) and p̂ (Sample Proportion) were calculated as follows (Wilson, 1927; Brown et al., 2001):

$$CI_{Wilson} = \frac{\hat{p}+\frac{z^2}{2n}\pm z\sqrt{\frac{\hat{p}(1-\hat{p})}{n}+\frac{z^2}{4n^2}}}{1+\frac{z^2}{n}} \quad \text{(Eq.1)}$$

$$\hat{p} = \frac{x}{n} \quad \text{(Eq.2)}$$

Where x is positive responses, n total number of responses, z is the z score (usually taken 1.96 for 95%).

Table 1 shows the estimated proportions (p̂) and Wilson 95 % confidence intervals for the indicators. Awareness for DT technology had the highest prevalence (0.74), whereas exposure to climate-resilience guidelines was extremely low of 0.08. A broad range confidence intervals was seen that reflects the small sample size but also emphasize the need for targeted training program. In Fig. 6, these stats and their confidence intervals were depicted.

Table 1. Statistical analysis of findings from the questionnaire

Indicator	p̂	95 % Wilson CI
Awareness of digital-twin technology	0.74	0.60 - 0.84
Use of digital-twin tools	0.38	0.26 - 0.51
Attendance of digital-twin courses	0.26	0.16 - 0.40
Access to climate-resilience guidelines	0.08	0.03 - 0.18
Attendance of climate-resilience training	0.02	0.00 - 0.10

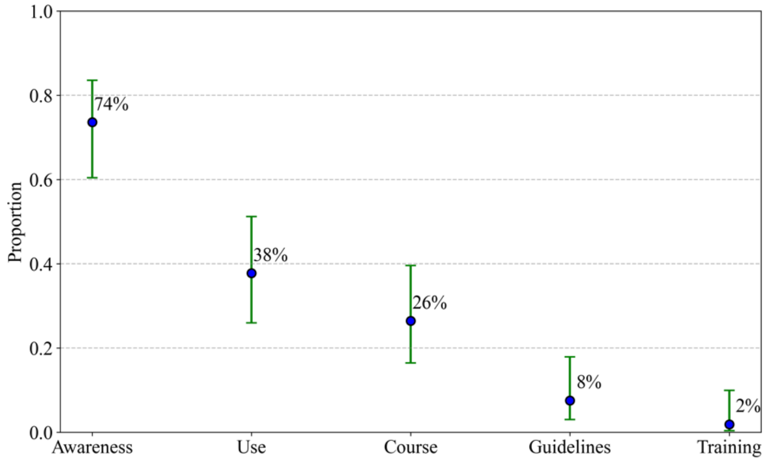

Figure 6. Wilson 95% confidence intervals for digital-twin familiarity indicators

DISCUSSION

Gap Between Awareness and Practical Adoption

The need analysis reveals a large discrepancy between awareness of DT technology and its practical use. Although nearly 75% of respondents have heard of before, only 38 % had used them and barely a quarter had attended a training course. This gap clearly indicates that there is a need for practical training. A training platform can behave as decent tool to learn digital representations of structures, enabling users understand how to visualize, control and simulate.

Limited Exposure to Climate-Resilience Applications

Despite fact that there is an interest in employ use of DT for climate resilience, the most of participants had no accessed to guidelines or training in this area, although the fact that DT can integrate in critical engineering systems to analyse flooding, urban heat and other climate related risks.

Interest in Applied Learning Materials

The most of participants stated their strong interest in learning resources, particularly case studies from real world DT applications. Such learning materials could help close the gap between awareness and practice. Similarly, having reach to guidelines and resources was found beneficial from the most of the responders. These needs matched with sustainability goals and support ongoing efforts to limit carbon emission in construction.

CONCLUSION

The needs analysis showed that young and future professionals in the civil and engineering sectors are familiar with the concept of digital twin technology. However, practical experience remains limited. Only very few participants have been involved in training or have benefited from guidelines for applying DT against to climate resilience, although these applications could serve as powerful tools for analysing heat, humidity, flooding, or other risks arising from climate change. Participants indicated a strong demand for case studies, basic learning materials, and curriculum-integrated guides. Although the relatively small sample size (n = 53) could be the limitation of this work, the balanced representation across target groups and countries still provides a useful knowledge of current awareness and training needs in civil engineering sector. Finally, open ended question answers collected from participants indicated a high demand for training tools supporting sustainability, material optimization, and extreme weather analysis needs that is matched with the European Union's green deal objectives. Different stakeholders including engineers, planners, and emergency managers can participate in active roles in digital twin interfaces for their needs. User-friendly visualization and interactive dashboards could make complex data more accessible, supporting timely and informed decision-making.

ACKNOWLEDGEMENTS

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Innovative Technologies for Plant Protection in Irrigation and their Application in Education

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ABSTRACT

The article analyses the essence, advantages and possibilities of using innovative technologies for plant protection in irrigation and their use in the educational process. The limited water resources and the impact of climate change necessitate the application of more efficient, environmentally sustainable and productive methods in agriculture. In this regard, drip and micro-irrigation systems, sensor technologies for measuring soil and air humidity, artificial intelligence-based management models, drone and satellite observation systems are of particular importance. These technologies play an important role both in protecting plants from diseases and pests and in minimizing the use of pesticides.

The study also shows that the integration of these technologies into the educational process is an effective tool for improving the knowledge and skills of students in engineering, agriculture and environmental specialties. The application of modern technologies in practical laboratory work, subject programs and training modules in higher and secondary specialized educational institutions allows for the formation of innovative thinking of future specialists, as well as the adoption of resource-saving and environmentally friendly approaches.

As a result, it was concluded that innovative technologies make a significant contribution both to increasing efficiency in agriculture and to developing practical skills in the educational process.

Keywords: *Precision irrigation, smart agriculture, electronic sensors, plant protection, water efficiency, education, education in agriculture.*

INTRODUCTION

Global climate change, population growth and increasing demand for agricultural products make the issue of food security even more urgent in the world. In these circumstances, increasing agricultural productivity, preserving ecological balance and efficient management of water resources have become important priorities. Irrigation systems are one of the most important factors in agriculture, but if not applied correctly, they lead to both water losses and a decrease in soil productivity. At the same time, protecting plants from diseases and pests is also important for the sustainable development of the agricultural sector. Since traditional methods do not provide full efficiency in this area, the application of innovative technologies is a necessity in the modern era.

In recent years, there has been a widespread application of drip and micro-irrigation systems, sensor technologies that measure soil and air humidity, artificial intelligence and drone-based monitoring systems in agriculture. These technologies not only ensure economical use of water, but also allow monitoring plant health, detecting diseases at an early stage and implementing timely protective measures. Such an approach creates conditions for both increased productivity and reduced use of pesticides and other chemicals, which is an important contribution to environmental sustainability.

The application of innovative technologies not only in practical agriculture, but also in the educational process is of particular importance. The integration of these technologies into lessons, laboratory work and practice areas in higher and secondary specialized educational institutions allows students to acquire modern knowledge and skills. Familiarity with sensor technologies, automated irrigation systems, artificial intelligence and drone applications of young people studying in engineering, agriculture and environmental specialties ensures that they will become more competitive specialists in the labour market in the future. In addition, such practical approaches contribute to the formation of innovative thinking in students and the development of the ability to find creative solutions to problems.

The main purpose of the article is to examine the essence and advantages of innovative technologies applied for plant protection in irrigation, as well as to consider the possibilities of their application in the education system. Analyses conducted in this direction show that innovative technologies have a significant impact not only on increasing productivity in agriculture, but also on improving the quality of education and strengthening the professional training of future specialists.

RESEARCH METHOD

Research Model

The research methodology used in the article is based on both theoretical and practical approaches. The purpose of the study is to identify the possibilities of innovative technologies for plant protection in irrigation and analyse the potential for their application in education. To achieve this goal, the following methods were used:

Literature analysis – International and local scientific articles, books, conference materials and regulatory documents on the topic were examined, and a theoretical basis for the application of innovative technologies in agriculture and the educational process was formed.

Comparative analysis – Traditional irrigation and plant protection methods were compared with innovative technologies, and their advantages and disadvantages were identified.[1]

Practical observation and case study – Real application examples of drip and micro-irrigation systems, soil moisture monitoring sensors, artificial intelligence-based management programs and drone technologies were examined.

Expert survey – Informal interviews were conducted among specialists and educators working in the agricultural field to learn their experiences and opinions on the current situation.

Educationally oriented analysis – The possibilities of applying innovative technologies in the curricula of educational institutions were studied, the effectiveness of practical laboratory work and training modules was assessed.

The results obtained on the basis of these methods showed the importance of the topic from both a scientific and pedagogical point of view, and it was determined that the integration of innovative technologies into the educational process plays an important role in the development of students' professional skills.

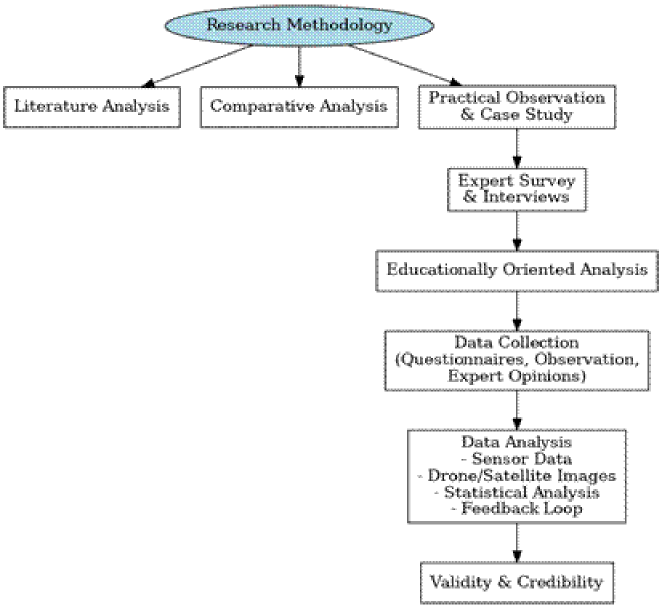

Figure 1. Research method diagram

Participants

Huseynov Elvin Elkhan - Graduated from Azerbaijan State Agrarian University with a degree in Electrical Power Engineering. (2015-2019). He graduated from the same university with a master's degree in Automated Electrotechnological Devices and Systems. (2019-2021). He is currently pursuing a doctoral degree in Electrical and Electronics Engineering at Karabük University, Republic of Turkey.

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Data Collection Tool

Various data collection tools were used to achieve the objectives of the study. The data collection process covered both theoretical and practical aspects and was based on both quantitative and qualitative approaches. This allowed for a more accurate assessment of both the scientific foundations of the topic and its real application possibilities.

1. Questionnaires

As part of the study, questionnaires were conducted among students studying in agriculture, engineering and ecology, as well as teachers teaching in these fields. Through the surveys, their knowledge levels about innovative irrigation technologies and plant protection methods, their attitudes towards the use of these technologies in the current educational process, and the degree of formation of practical skills were studied. The questionnaires included open and closed questions, and objective indicators were obtained as a result of statistical processing of the answers.[2]

2. Interviews

In the qualitative part of the study, semi-structured interviews were organized with agricultural specialists, farmers and educators. The main focus of the interviews was on the difficulties encountered during the practical application of innovative technologies, their advantages and experiences related to the integration of these technologies into the educational process. This approach allowed for the study of real field experience and the preparation of proposals that could be applied in the educational environment.

3. Observation

The application of drip and micro-irrigation systems, soil and air humidity monitoring sensors, artificial intelligence-based management programs and drone technologies in real agricultural fields was studied through the observation method. In this process, the effectiveness of the technologies, limitations in the field of application and their potential opportunities for adaptation to the educational process were recorded.

4. Literature and document analysis

As one of the data collection tools, articles published in international scientific journals, conference materials, state programs, strategic documents on the development of the agricultural sector and existing curricula were examined. As a result of the literature analysis, the theoretical foundations of the topic were formed, and comparisons were made between global experience and local conditions.

5. Expert opinions

In addition, written and oral expert opinions were obtained from experts in the field. The experts expressed valuable opinions on the practical effectiveness of technologies, their application possibilities in the education system, and future development prospects.

Thus, the use of various data collection tools allowed for the study of both theoretical and practical aspects of the topic, increasing the objectivity and reliability of the results. [3]

Collection of Data

These data collection tools are integrated into a microprocessor-based control unit, resulting in accurate, economical, and environmentally sustainable irrigation.

Data Analysis

The data collected during the study were systematically analysed and evaluated for the purpose of optimizing the irrigation process. The analysis is based on indicators obtained through electronic sensors, drone monitoring and mobile applications.

The analysis stages were carried out as follows:

1. Sensor data processing – Data from soil moisture, temperature and light intensity sensors are collected and analysed by a microprocessor. The water needs of plants are determined based on this data.

2. Drone and satellite image analysis – Humidity, vegetation status and water distribution uniformity across the area are assessed using drone and satellite images. This allows for proper management of irrigation zones.

3. Statistical analysis – Water consumption, productivity indicators and energy costs were evaluated using statistical methods. Comparative analysis shows that the application of electronic technologies increases water consumption by 30-40% and productivity by 20-25%.

4. Feedback analysis – The system automatically analyses the results obtained and improves the irrigation plan. This helps protect plants by ensuring optimal water distribution.

Conclusion: The analysis shows that electronic sensors and automated systems allow for more accurate and economical irrigation in agriculture, as well as increasing plant health and productivity

Validity and Credibility

The reliability of the research results was ensured by several factors. First, the data collection tools – soil moisture sensors, temperature and light sensors, drone monitoring and electronic filtration systems – were selected and calibrated in accordance with international standards. This ensures the accuracy and repeatability of measurements. Secondly, automated systems were used in the data collection and processing process. Microprocessors and control units analyse the signals from the sensors in real time and minimize errors caused by the human factor. Thirdly, statistical analysis and comparative analysis methods strengthened the objectivity of the results. The results obtained were confirmed by comparison with both traditional irrigation methods and electronics-based systems. Fourthly, practical examples and experimental observations showed the validity of the research results in the applied conditions. Tests conducted in various fields and in different climatic conditions confirmed the stable and reliable operation of electronic technologies. As a result, the reliability of the research was ensured by both the quality of the technologies used and the systematic and objective analysis of the data. This indicates that the results presented in the article are suitable and reliable for practical application.

FINDINGS

As a result of the research, it was determined that innovative irrigation technologies based on electronics have significant advantages in terms of plant protection and increased productivity.

1. Water saving: Water consumption can be reduced by 30-40% compared to traditional methods through drip irrigation systems, electronic valves and sensors. This is important both economically and environmentally.

2. Productivity increase: Real-time monitoring of soil moisture and other indicators increases productivity by 20-25%. Since optimal irrigation is carried out in accordance with the growth stages of plants, the quality of the product also increases.

3. Plant protection: Sensor-based alarm systems against pests, automatic fogging and filtration technologies increase the resistance of plants to diseases and stress factors.

4. Reduction of labour and energy costs: Automated control units and mobile monitoring systems allow the irrigation process to be carried out with minimal human intervention. This optimizes both labour costs and energy consumption.

5. Ecological sustainability: Accurate and planned irrigation prevents soil salinization and maintains ecological balance.

As a result, electronics-based irrigation technologies form the basis of sustainable, economical and productive irrigation in agriculture. The application of these systems is one of the promising directions for the modernization and digitalization of the agricultural sector in our country

DISCUSSION AND CONCLUSION

The results of the study show that innovative irrigation technologies based on electronics make a significant contribution to both increasing productivity and protecting plants in agriculture. Through sensors, automated control units and drone monitoring, indicators such as soil moisture, temperature and light intensity are monitored in real time, and the irrigation process is optimized. During the discussion, it was found that electronic control of drip irrigation systems minimizes water losses and ensures water distribution according to the needs of plants. At the same time, accurate and planned irrigation prevents soil salinization and serves to maintain ecological balance. As a result, electronics-based irrigation technologies play a key role in implementing sustainable, economical and productive irrigation in agriculture. The application of these technologies is one of the promising directions for the modernization, digitalization and environmental sustainability of the agricultural sector in our country. In the future, the integration of artificial intelligence and IoT systems will allow for further improvement of this process. [4]

Impacts on education:

Development of practical skills: Measuring indicators such as soil moisture, temperature and light intensity with sensors in laboratory classes allows students to apply their knowledge in a practical way.

Formation of digital skills: The use of drones and mobile applications ensures that young specialists acquire digital skills in accordance with the concept of “Smart Agriculture”.

Innovative thinking and problem solving: Analysis of data collected in real time develops data-based decision-making, analytical thinking and problem-solving skills in students.

Interdisciplinary approach: Teaching irrigation technologies in connection with engineering, ecology and information technologies forms a complex way of thinking in students.

Preparation for the labour market: The ability to work with electronics-based systems allows students to become competitive specialists in the agricultural field by applying modern technologies in the future.

As a result, the integration of these technologies into the educational process ensures that students are equipped not only with theoretical knowledge, but also with real field skills. Thus, electronics-based irrigation systems not only support sustainable development in agriculture but also become an integral part of modern teaching methodology and serve to train future agricultural specialists.

Suggestions

The application of innovative technologies based on electronics for the efficient organization of irrigation and plant protection in modern agriculture reveals a number of recommendations. Farmers should use soil moisture, temperature and light intensity sensors, and the irrigation process should be monitored in real time. Drip irrigation systems should be combined with electronic valves to ensure optimal water distribution.

Drone and satellite technologies should be used to monitor irrigation and plant protection processes in large areas. Sensor-based signalling systems and automatic fogging technologies should increase the resistance of plants to diseases and stress factors. Modern IoT platforms and mobile applications should be widely used for farmers to remotely monitor and control irrigation. [5]

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Emerging Competencies in the Logistics Sector in the Context of Digitalization in Sustainability: Analysis of Turkey Case Studies from the EARTH Project[1]

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ABSTRACT

Developments in the transportation and communications sectors, along with globalization, have expanded the scope of trade and accelerated human mobility. In parallel with this transformation, logistics sector operations are growing rapidly. The logistic sector, one of the major contributors to environmental impact, is undergoing a transformation through sustainability-oriented digitalization. This transition requires not only operational expertise but also new digital competencies from logistics professionals. Within this context, this study—conducted as part of the Erasmus+ EARTH (Ethical and Responsible Transportation and Handling) Project— examines how sustainability and digitalization practices reshape competency requirements in the logistics sector and aims to identify best practices for future training programs. This research analysis a case study based on semi-structured interviews conducted with three logistics companies operating in Turkey as part of the EARTH project. Data analysed through content analysis within the scope of the qualitative research revealed emerging competencies in the logistics sector. According to the findings, while compliance with legislation and standards, reducing environmental impact, developing sustainability strategies, and social inclusion are prominent within the context of sustainability, digital literacy, data management, automation of business processes, software development, innovation management, and digital customer relations have been identified as core competency areas within the context of digitalization. The results show that digitalization and sustainability practices are implemented differently depending on the company's size and management culture.

[1] Project Ethical and Responsible Transportation and Handling, implemented from 2023-12-31 to 2025-12-30, supported under Erasmus+ program, Agreement No. 2023-1-PL01-KA220-HED-000160734.

While startups adapt quickly, resource constraints slow down the process in family businesses, and multinationals utilize global standards to demonstrate more advanced practices. The study contributes to the understanding of next-generation competencies in the logistics sector and guides the design of training programs for higher education institutions and industry professionals.

Keywords: *Sustainability, digitalization, logistics sector, competencies, EARTH project.*

INTRODUCTION

Driven by globalization and technological developments, international trade has expanded rapidly while becoming more complex and volatile, making logistics operations increasingly critical to global value chains. However, the rapid growth of logistics activities has also intensified environmental concerns, energy consumption, and social challenges, placing growing pressure on the sector to operate more sustainably (Sarkis, 2021; McKinnon, 2018). At the same time, digital technologies such as automation, data analytics, and artificial intelligence are reshaping logistics operations by enhancing efficiency, transparency, and real-time decision-making (Koh & Yuen, 2022). Consequently, the logistics sector is experiencing a dual transformation, driven by the global agendas of sustainability and digitalization.

Traditionally, sustainability initiatives in logistics have been motivated by regulatory compliance and risk mitigation. Yet, recent research emphasizes that long-term competitiveness increasingly depends on a company’s capacity to integrate sustainability into strategic and operational capabilities (Abbasi & Nilsson, 2016; Sun et al., 2022). Similarly, digitalization has evolved beyond a technological upgrade into a strategic capability domain that requires workforce adaptation, organizational learning, and process redesign (Woschank et al., 2020). Despite these advances, many logistics firms—especially in emerging economies—struggle to integrate digital and sustainable transformation holistically, often treating them as separate rather than mutually reinforcing agendas (Katsaliaki et al., 2021). Against this background, a key question arises: What competencies are required for logistics professionals to navigate the intersection of sustainability and digitalization, and how do these competencies evolve across different organizational contexts? Addressing this question is vital not only for firms aiming to build future-ready workforces but also for higher education institutions and policymakers developing training frameworks aligned with industry transformation. This study explores emerging competency requirements in the logistics sector through an exploratory multiple case study conducted within the EARTH (Ethical and Responsible Transportation and Handling) Project under the Erasmus+ initiative. By examining logistics firms of different sizes and governance structures operating in Türkiye, the research captures variations in competency development and identifies alignment challenges between technological adoption and human capital readiness. The findings contribute to the conceptualization of next-generation logistics competencies, offering both theoretical insights and practical guidance for skills development in the era of green and digital transformation.

LITERATURE REVIEW

Sustainable Logistics: Evolution, Concepts, and Frameworks

The concept of sustainability gained global importance particularly after the Industrial Revolution, as environmental degradation resulting from rapid technological development and population growth became increasingly evident. The environmental crises of the 1960s triggered growing public awareness of pollution and ecological balance, while in the 1980s, the integration of development and intergenerational equity principles laid the foundations for sustainable development. The Brundtland Report (WCED, 1987) defined *sustainability as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* Since the 1990s, the monitoring of environmental indicators and the reporting of sustainability performance have become widespread, institutionalizing sustainability within corporate and policy frameworks.

Over the past three decades, global sustainability efforts have been reinforced by international agreements and policy initiatives. The United Nations Sustainable Development Goals (SDGs), adopted in 2015, established a universal framework encompassing environmental protection, economic inclusion, and social well-being. Similarly, the Paris Climate Agreement introduced binding global targets for greenhouse gas emission reduction, and the European Green Deal accelerated the transition toward a low-carbon and circular economy. These global frameworks have exerted significant influence on the logistics sector by promoting energy efficiency, alternative fuel adoption, and low-emission transportation models (Sun et al., 2022; European Commission, 2023).

The logistics sector, which largely depends on fossil fuels for transportation and distribution, is one of the primary contributors to global carbon emissions (Senir & Büyükkeklik, 2017). Consequently, developing effective sustainability strategies is critical to reducing its environmental impact. From an economic standpoint, logistics acts as a fundamental driver of trade competitiveness, productivity, and national growth (World Bank, 2022). However, socially, logistics operations generate employment opportunities while also raising concerns regarding occupational safety, gender disparities, and precarious employment conditions (Nguyen & Notteboom, 2022). Therefore, sustainable logistics must be addressed through a multidimensional framework encompassing environmental, economic, and social dimensions—commonly referred to as the Triple Bottom Line (Elkington, 1998).

Within this framework, sustainable logistics can be defined as the design, coordination, and management of logistics processes aimed at minimizing environmental harm while ensuring economic performance and social welfare (Srivastava, 2007; Jayarathna et al., 2023). This holistic approach aligns with the SDGs' principles, which emphasize not only environmental protection but also decent work, inclusiveness, and innovation (Sun et al., 2022). Companies that successfully integrate sustainability into their logistics strategies not only enhance efficiency and resilience but also gain competitive advantages in the global market. For instance, MAERSK, in pursuit of its carbon-neutral targets, has developed biofuel- and methanol-powered vessels, rapidly adapting to emerging emission regulations and demonstrating how sustainability can serve as both an environmental and strategic advantage (Maersk, 2023).

In summary, sustainable logistics represents a strategic transformation rather than a regulatory obligation. It requires integrating environmental responsibility, digital efficiency, and social inclusion into every stage of the supply chain. As logistics firms increasingly adopt this multidimensional approach, sustainability becomes not only an ethical imperative but also a catalyst for innovation, competitiveness, and long-term value creation (Abbasi & Nilsson, 2016; Sarkis, 2021).

Digitalization in Logistics and Its Role in Sustainability

Logistics today is strongly oriented towards digitalization as a result of competitive pressure, the need to meet customer expectations, adaptation to regulatory requirements (e.g., the EU Green Deal, Fit for 55), as well as the growing availability of digital technologies. In modern logistics systems, digitalization is no longer limited to individual IT systems but encompasses entire supply chains and operational processes, leading to the emergence of Digital Supply Chains (Ageron et al., 2020). This transformation involves the implementation of a wide range of integrated and interoperable digital technologies, among which the most significant including IoT, AI, cloud computing robotics, and blockchain technologies and among others. (Finke & Schumann, 2025; Lu & Taghipour, 2025; Massari, et al., 2025; Živičnjak, et al., 2025; Dyczkowska, et al., 2024; Jan, et al., 2024; Lackner, et al., 2024; Waduge, et al., 2024; Zhang, et al., 2024; Khan, et al., 2022; Tan & Sidhu, 2022). These technologies enhance efficiency and support sustainable development. The strong trend of using these technologies aligns with the guidelines and principles of sustainable development, providing robust support for achieving the Sustainable Development Goals (SDGs) (United Nations, 2024).

The SDGs have significantly influenced actions aimed at protecting the environment, mitigating climate change, reducing harmful emissions, improving resource efficiency, and optimizing energy consumption, as well as enhancing safety and working conditions. In logistics, the SDGs drive innovations in supply chain management processes such as, warehousing, material handling and among others (Shamout, 2024; Romagnoli, et al. 2023; Aravindaraj & Rajan Chinna, 2022; Malinowska, 2022; Santhina, et al. 2021; Bartolini et al., 2019; Yakovleva, 2019; Wichaisri & Sopadang, 2014). The application of digital technologies is particularly pronounced in relation to Goal 7,9,11,12 and 13.

Technologies such as the Internet of Things (IoT), vision systems, Big Data and Artificial Intelligence (AI/ML), as well as digital twins, enable the simulation of different lighting, heating, and ventilation scenarios depending on workload intensity and external conditions, and allow for monitoring and analysing energy consumption patterns, predictive control of HVAC and lighting systems, and energy optimization. They also support dynamic testing of route options, schedules, weather conditions, and traffic, as well as real-time resource management, thereby contributing to the development of clean and energy-efficient logistics systems and the reduction of harmful emissions (Goals 7, 12, and 13) (Mohsen & Mohsen, 2025; Jubrail, et al., 2024; Liu, et at., 2024). Cloud and edge computing, 5G/LPWAN communication technologies, and advanced IT management systems enhance the resilience and innovativeness of logistics infrastructure, provide connectivity for millions of IoT devices essential for tracking shipments, containers, and pallets, enable inventory reduction and waste minimization, and allow data processing close to its source (e.g., in vehicles, warehouses, and terminals), aligning with the objectives of Goals 9 and 12 (Dyczkowska et al., 2024; Apruzzese, et al., 2023). In turn, technologies such as blockchain, robotics (AGV/AMR), RPA/IPA, and 3D printing (Additive Manufacturing) support the transformation towards circular logistics and responsible production and consumption patterns (Goal 12), among others, through supply chain transparency, local production, data sharing between multiple stakeholders, and inventory reduction, efficient packaging management, and the automation of administrative, warehousing, and internal transportation processes (Keskin, et al., 2025; Lackner, et al., 2024; Romagnoli, et al., 2023; Khan, et al., 2022). Meanwhile, Urban logistics that leverages IoT, data analytics, and transport automation contributes to the development of more sustainable and resilient urban systems, capable of monitoring traffic, the condition of infrastructure and vehicles, and optimizing traffic intensity and routes, as well as analysing different transport and spatial scenarios (Goals 11 and 13) (Mohsen, 2024; Ridaoui, et al., 2024; Santhina, et al. 2021).

The presented examples demonstrate a mutually reinforcing relationship between technological progress and sustainable development, where technologies support the achievement of environmental, social, and economic goals, while sustainability objectives, in turn, accelerate innovation. However, implementing sustainable solutions depends on factors such as policies and regulations, regional adaptation needs, innovation costs, strategies, and management practices. Technological capability and expertise are also essential, given the rapid progress and complexity of new technologies. Companies in complex supply chains must integrate various technologies and establish shared sustainability goals with partners, which requires openness and social awareness, as social norms can either support or hinder sustainable development (Singh & Maheswaran, 2023; Chauhan et al., 2022; Ageron et al., 2020).

Furthermore, when it comes to digitalization, recent data reveal a significant technology adoption gap between SMEs and large enterprises. As strongly emphasized in the European Commission's DESI 2022 and 2023 reports, companies in the EU have adopted advanced digital technologies, such as cloud computing, big data analytics, IoT, or mobile business applications, only to a limited extent (European Commission, 2022 and 2023). The gap is particularly visible among micro and small service-oriented companies, which often lack both financial resources and digital competencies necessary for effective implementation (OECD, 2022; Nowak, 2020). This uneven digital transformation trajectory poses a serious challenge to achieving balanced progress across sectors and regions. Bridging these gaps requires not only a comprehensive approach, joining technological investment with supportive policy frameworks and funding, but also the transfer of knowledge and innovations through education programs and collaboration between the supply chain stakeholders.

Competency Models in Sustainable and Digital Logistics

The convergence of sustainability pressures and logistics digitalization has led to a paradigm shift in the definition and structuring of professional competencies. Traditional competency frameworks in logistics — largely centred on operational efficiency, technical knowledge, and regulatory compliance — are no longer sufficient. Instead, emerging competency models emphasize a hybrid structure, integrating digital, environmental, managerial, and social dimensions in a coherent system (Koh & Yuen, 2022; Katsaliaki et al., 2021; Albrecht et al., 2023).

Recent literature classifies competencies in four major clusters suitable for sustainable and digital logistics: *technical and logistics capabilities*, *digital literacy*, *sustainability expertise*, and *soft skills for collaboration and change management*. This categorization is widely supported across multiple studies, particularly within the frameworks of Industry 4.0 logistics competencies (Koh & Yuen, 2022; Albrecht et al., 2023), green and circular supply chain capability models (Martinsen & Huge-Brodin, 2014; Vilela et al., 2018), and workforce transition research in ESG-oriented logistics (Cantoni et al., 2024). Rather than functioning as isolated skill domains, these competencies operate as an interdependent matrix that enables logistics professionals to navigate technological transformation while adhering to environmental and social expectations, reflecting what Katsaliaki et al. (2021) define as *"dual digital–sustainability readiness"* within modern logistics roles.

Importantly, competency evolution is not linear but highly contextual. Organizations at different maturity levels display different adaptation pathways. Newly founded or innovation-oriented logistics firms tend to adopt digital tools rapidly but often lack structured sustainability governance (El Baz & Laguir, 2024). Family-owned or traditional small and medium-sized enterprises rely heavily on experiential knowledge yet struggle to translate such expertise into codified digital practices. In contrast, multinational firms apply advanced competency architectures aligned with global frameworks such as the European Logistics Association Standards and ESG-aligned corporate reporting, integrating structured training modules, leadership development schemes, and performance metrics (Cantoni et al., 2024; Martinsen & Huge-Brodin, 2014). This differentiation suggests that competency frameworks should not be monolithic but tiered and adaptable according to organizational size, ownership model, and strategic orientation.

The dual transition toward digitalization and sustainability is redefining the traditional roles of logistics employees. Rather than functioning merely as transactional coordinators or fleet supervisors, professionals in the sector are increasingly expected to operate as data-enabled decision-makers, sustainability strategists, and ecosystem integrators (Koh & Yuen, 2022; Katsaliaki et al., 2021). Emerging roles such as *digital logistics coordinators, sustainability compliance officers, innovation mediators,* and *cold chain risk analysts* illustrate this shift toward techno-managerial responsibilities. These roles require a cross-functional blend of data analytics, regulatory awareness, customer experience orientation, and predictive risk management, indicating that logistics careers are moving from operational execution toward strategic orchestration.

Despite growing awareness of sustainability and digital transformation imperatives, the human capital infrastructure within the logistics sector remains underdeveloped. A persistent digital literacy gap is evident across workforce levels, as many logistics employees are introduced to advanced systems such as ERP, AI-based platforms, or automated reporting tools without adequate training frameworks to ensure long-term adoption (El Baz & Laguir, 2024; Woschank et al., 2020). Moreover, sustainability consciousness is frequently approached from a reactive compliance perspective rather than being embedded as a strategic value proposition, which limits proactive innovation (Martinsen & Huge-Brodin, 2014). Beyond technical skills, the most significant bottlenecks appear in change management, cross-departmental collaboration, and visionary leadership, all of which are critical for managing the socio-technical transition (Katsaliaki et al., 2021). Compounding these issues is the widespread absence of structured competency frameworks and continuous learning mechanisms. Existing training programs are often short-term, task-based, and disconnected from broader organizational transformation strategies, preventing employees from aligning digital proficiency with sustainability objectives in a consistent manner (Vilela et al., 2018; Prajogo et al., 2022).

METHODOLOGY

This study adopts a qualitative multiple case study design, which is widely recognized as an effective approach for exploring complex socio-technical transitions in organizational settings (Yin, 2014; Stake, 1995; Eisenhardt, 1989). A qualitative design enables the examination of how sustainability and digitalization are interpreted, enacted, and operationalized by different actors within the logistics sector—an approach recommended in supply chain and sustainability research where context and perception play pivotal roles (Seuring & Müller, 2008; Sarkis, 2021).

Case Selection and Sampling Strategy

The research employs a purposeful sampling strategy (Patton, 2015; Palinkas et al., 2015) to ensure variation across organizational size, ownership structure, and transformation maturity. Three logistics firms operating in Türkiye were selected: *FIRM1* (technology-driven SME), *FIRM2* (family-owned medium enterprise), and

FIRM3 (multinational corporation with institutionalized ESG structures). This heterogeneous sampling logic aligns with comparative case methodology standards that aim to generate analytical—not statistical—generalization (Eisenhardt & Graebner, 2007; Flyvbjerg, 2006).

Data Collection Methods

Data were collected through semi-structured interviews, which are widely recommended for exploratory research where flexibility and depth are required (Kallio et al., 2016; Brinkmann, 2013). This format allowed respondents to articulate their interpretations of sustainability, digital transformation pressures, competency expectations, and workforce challenges while enabling the researcher to probe into firm-specific practices and perceptions. In addition to interviews, secondary data sources—including corporate sustainability reports, official websites, press releases, and professional networking content—were examined to triangulate declared strategies with publicly communicated narratives (Bowen, 2009; Flick, 2018). The combination of self-reported insight and documentary evidence strengthens the credibility of interpretation while minimizing single-source bias (Denzin, 2012; Jick, 1979).

Data Analysis Procedure

The collected data were analysed using thematic analysis following the six-stage framework proposed by Braun and Clarke (2006), which is considered one of the most robust methods for interpreting qualitative organizational data (Nowell et al., 2017; Castleberry & Nolen, 2018). Initial deductive codes were derived from competency clusters identified in the literature—namely *technical/logistics, digital, sustainability, and soft skills* (Koh & Yuen, 2022; Albrecht et al., 2023). However, inductive coding was also applied to capture context-specific themes, such as *"regulation-driven sustainability," "symbolic commitment," or "digital resistance at operational level."* Comparative patterning across firms followed Eisenhardt's (1989) logic of "within-case" and "cross-case" analysis to reveal systemic variances by organizational type.

Trustworthiness and Research Validity

To enhance methodological rigor, credibility and transferability were ensured through standard qualitative validation strategies (Lincoln & Guba, 1985; Shenton, 2004). Data triangulation was achieved by cross-verifying interview statements with secondary documentation, while methodological transparency was maintained through detailed memoing during coding (Miles, Huberman & Saldaña, 2014). The findings provide analytical, rather than statistical, generalizability (Yin, 2014), offering transferable insight into how logistics firms in emerging economies negotiate the dual pressures of digitalization and sustainability (Prajogo et al., 2022; Woschank et al., 2020).

FINDINGS

Drivers of Digital and Sustainable Transformation: Market Pull or Regulatory Push?

The empirical analysis reveals that the primary driver of sustainability and digitalization efforts within the Turkish logistics sector is regulatory compliance rather than market demand or strategic differentiation. Contrary to the dominant discourse in the literature suggesting that firms increasingly adopt environmental and digital innovations for competitive positioning or customer legitimacy (Sarkis, 2021; Abbasi & Nilsson, 2016), the interviewed companies emphasized pressure from EU transport regulations, carbon reporting obligations, and customs digitalization mandates as the main stimuli for transformation. While international frameworks such as the EU Green Deal and Fit-for-55 were well recognized, none of the participating firms indicated substantial consumer or business partner pressure toward greener logistics. This suggests that in emerging economies such as Türkiye, sustainability transitions are policy-led rather than market-led, resulting in reactive adaptation rather than proactive innovation.

Competency Alignment and Mismatch Across Organizational Profiles

The comparison of cases demonstrates significant variation in competency development trajectories depending on firm structure and maturity. In the technology-oriented SME (FIRM1), digital capabilities such as automation and data monitoring were relatively advanced, yet sustainability competencies remained symbolic and unstructured. In the family-owned mid-scale enterprise (FIRM2), long-standing operational expertise existed but was not systematically translated into codified digital or environmental performance models. By contrast, FIRM3, as a multinational corporation, exhibited a globally standardized competency architecture, integrating digital training modules, ESG performance indicators, and structured internal upskilling programs. These findings align with prior research suggesting that competency evolution is not linear but contingent on ownership model, managerial culture, and exposure to international networks (El Baz & Laguir, 2024; Flyvbjerg, 2006). Accordingly, rather than assuming a universal skill model, the results point toward the need for tiered competency frameworks tailored to different maturity levels.

Integration Gap Between Digitalization and Sustainability Strategies

Despite the expanding academic emphasis on dual digital–sustainability readiness (Katsaliaki et al., 2021), the findings indicate that in practice, digitalization and sustainability are pursued as parallel but disconnected agendas. Digital tools such as ERP platforms, real-time monitoring, or AI-based interfaces are predominantly adopted for efficiency and cost reduction, whereas sustainability initiatives are implemented for compliance and certification purposes. None of the analysed firms reported systematic integration of digital technologies as enablers of environmental performance, such as carbon data analytics or predictive emission reporting. This fragmentation suggests that the transformational potential of digital tools remains underutilized and that sustainability is still perceived as an add-on function rather than a digitally embedded operational logic.

Human Capital Readiness and Learning Barriers

Across all cases, human capital emerged as the most critical constraint in achieving alignment between sustainability and digitalization objectives. Echoing findings in broader logistics literature (Woschank et al., 2020; Prajogo et al., 2022), firms reported limited digital literacy among operational staff, resistance to new work models among first-generation managers, and insufficient cross-departmental collaboration for transformation efforts. Although technological investments such as ERP and AI platforms were made, lack of structured training frameworks and absence of continuous learning mechanisms often prevented these tools from being fully utilized. Training activities, when present, were short-term and task-oriented, rather than linked to strategic competency planning. This reinforces the broader insight that technology acquisition does not automatically translate into capability development, and that cultural and educational infrastructures remain decisive bottlenecks in logistics transformation.

CONCLUSION AND RECOMMENDATIONS

This study has demonstrated that the transformation of the logistics sector under the dual pressures of sustainability and digitalization is not merely technological, but fundamentally competency-driven. While greening initiatives and digital tools are increasingly adopted across logistics operations, their effectiveness largely depends on the capabilities, adaptability, and learning capacity of the workforce. The findings reveal that competency evolution is highly contextual, varying significantly across firm typologies: *startups exhibit agility but lack institutionalization, family-owned firms rely on experiential know-how yet face resistance to digital training, while multinational firms perform better due to structured frameworks and global governance models.*

A key insight is that sustainability and digitalization are often pursued as parallel but disconnected agendas, rather than being strategically integrated. This fragmentation risks reducing sustainability to a compliance activity and digitalization to a cost-efficiency tool—thus limiting their transformative potential. To overcome this, logistics firms must shift from tool-oriented adoption to capability-oriented integration, embedding both sustainability and digitalization into strategic planning, performance metrics, and talent development systems.

Based on the results, several recommendations can be made for both industry and higher education stakeholders. Firms should establish competency development roadmaps that align with their level of transformation maturity, replacing generic training practices with tiered learning models that distinguish between operational, tactical, and strategic competency needs. Rather than treating digital tools such as ERP or AI platforms as standalone investments, organizations should couple them with continuous learning schemes, mentorship mechanisms, and structured change management leadership to ensure meaningful adoption. In parallel, higher education and vocational training institutions must redesign logistics and supply chain curricula to transcend purely technical instruction by incorporating sustainability governance, digital literacy, data interpretation, and cross-functional collaboration. Stronger collaboration between academia and industry—through apprenticeship programs, living labs, and micro-credential frameworks—would accelerate alignment between emerging competency requirements and workforce preparation.

For policymakers, national and regional authorities should prioritize the creation of competency certification systems that integrate sustainability standards such as SDG and ESG criteria with digital transformation benchmarks. Public incentives should not focus solely on technological investments but also on strengthening human capital, particularly within small and medium-sized enterprises that lack the institutional capacity to design structured training programs. By aligning industrial strategy, education policy, and regulatory frameworks around competency development, the logistics sector can move toward a more cohesive and future-ready transformation model.

In conclusion, the logistics sector's transition towards a sustainable and digital future depends less on *technological availability* than on *human capability readiness*. Future research should continue to explore how different institutional, cultural, and regulatory environments shape competency evolution, expanding the comparative scope beyond Türkiye to other emerging economies. By placing competencies at the centre of transformation, logistics can move from reactive adaptation to strategic leadership in the sustainability era.

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Innovative Curriculum to Evaluate Marine Fishery Discards as Raw Pet Food - MARIPET

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ABSTRACT

Fishery discards, estimated at 7-10 million tonnes annually, represent a critical ecological and economic challenge. This study addresses this issue by exploring the valorisation of discarded marine fish as a primary protein source for the pet food industry, specifically for producing Biologically Approved Raw Food (BARF). The MARIPET project developed an innovative curriculum to bridge the knowledge gap among fisheries and pet industry professionals. A needs analysis survey of 267 participants, including veterinarians, fisheries engineers, and food engineers, revealed significant knowledge gaps regarding discards, BARF production, and relevant EU legislation on biosafety and hygiene. Despite this, a strong consensus emerged on the potential of using discards as raw material and a clear preference for visual, web-based training. In response, a flexible training program was designed, comprising five core modules that cover the entire value chain from discard identification to final BARF product compliance. The project demonstrates a viable pathway to mitigate an environmental problem by creating a sustainable, circular supply chain, turning a costly waste stream into a valuable resource for the growing pet food market while supporting broader sustainability goals.

Keywords: *Fishery discards, BARF, pet food, sustainable aquaculture, circular economy, vocational training.*

INTRODUCTION

Over three billion people depend on marine and coastal biodiversity for their livelihoods, yet 30 percent of the world's fish stocks are currently overexploited. According to the Food and Agriculture Organization (FAO, 2020), total global fish production reached 179 million tonnes in 2018. While 88% of this was utilized for direct human consumption, the remaining 12% was designated for non-food purposes or classified as waste. A critical component of this waste is fishery discards, commercial fish that are caught and then thrown back into the sea, often dead or dying. It is estimated that between 7 and 10 million tonnes of catches are discarded annually (Kelleher, 2005), representing a significant ecological problem and a substantial economic loss.
Reducing by-catch and discards is therefore a paramount issue for sustainable fishery management (Bianchi

et al., 2008). Despite efforts by fisheries engineers to improve gear selectivity, the challenge persists, particularly in multi-gear and multi-species fisheries (Bellido et al., 2011) such as those in the Mediterranean, where up to 35% of the total catch biomass may be of low or no commercial value. In this context, strategic solutions are urgently needed to address the dual pressures of a growing global population and declining food resources. Policies like the EU's Reformed Common Fisheries Policy (European Commission, 2013), which mandates that all discarded catches be brought to shore, further underscore the necessity of finding viable uses for this material.

This study proposes to address this issue by valorising fishery discards as a primary protein source in the pet food industry (Belluco et al., 2013), specifically for the production of Biologically Approved Raw Food (BARF). Although BARF diets are well-established (Freeman et al., 2013), the use of fishery discards as a key ingredient is a novel approach. The MARIPET project aims to bridge the knowledge gap by developing an innovative curriculum and training program for fisheries and pet industry professionals. The ultimate goal is to create a sustainable, ecosystem-friendly supply chain that introduces discarded fish into the rapidly growing European pet food market, simultaneously mitigating an ecological burden and creating economic value, thereby supporting broader objectives such as the United Nations' Sustainable Development Goal 14: "Life Below Water" (United Nations, 2015).

RESEARCH METHOD

Research Model

The curriculum development for this study was guided by a framework that meticulously outlined the nature and purpose of each course, with a central focus on aligning content with specific learning objectives and outcomes—namely, knowledge, skills, and competencies. This process involved creating clear and actionable learning outcomes for five core modules: 1) Introduction to fishery discards and their evaluation, 2) Discarded species and methods for reduction, 3) Innovations in processing discards, 4) Using discards to produce pet food, and 5) Biosecurity, hygiene, and relevant EU legislation. The selected methodology prioritized effectiveness in describing, using, and applying these learning outcomes, aiming to enhance the transparency, understanding, and comparability of the qualifications offered within each module. This template served as the foundational guideline for developing all MARIPET learning materials. In a theoretical sense, the curriculum encompassed the content of the courses, while more broadly, it addressed the knowledge, attitudes, behaviours, performance, and skills to be instilled in learners through various teaching methods, assignments, exercises, study materials, and presentations.

Participants

A comprehensive needs analysis was conducted at the initial stage, informed by state-of-the-art national and international reports. The analysis targeted key sectoral professionals, including Fisheries and Aquaculture Engineers/Experts, Veterinary Specialists, Fishermen, Food and Agricultural Engineers, and Pet Food Producers. A statistical study of 267 participants generated a narrative Training Needs Analysis report (Figure 1).

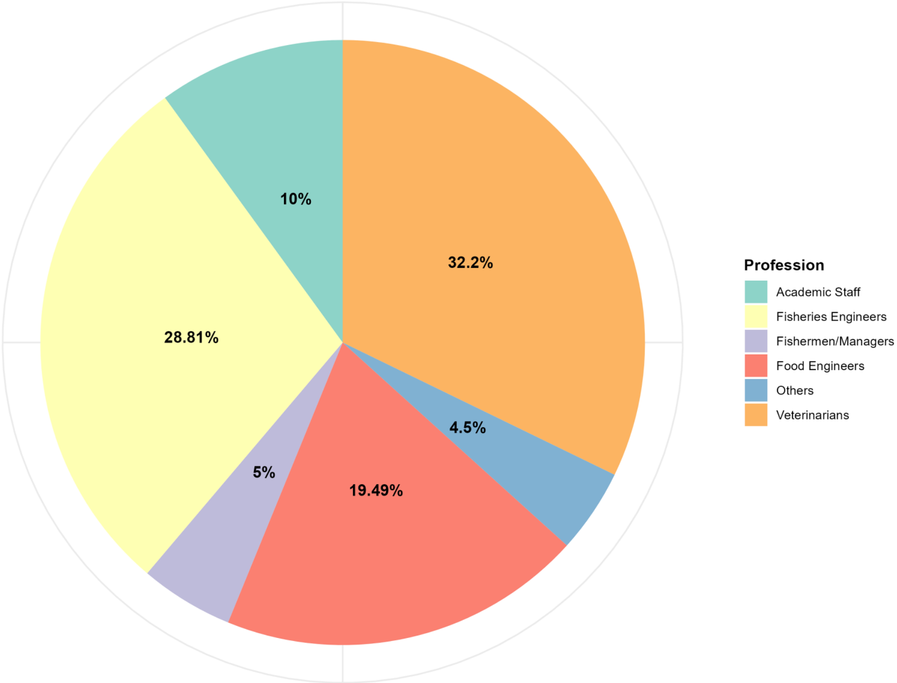

Figure 1. Demographic and Professional Distribution of Survey Participants (N=267).

The participant demographic was diverse: 37.35% were over 40 years old, and 31.91% were in the 21-30 age range, with a gender distribution of 50.58% male and 38.13% female. Academically, 49.80% held undergraduate degrees, while 22.45% held MSc degrees and another 22.45% held PhDs. Veterinarians formed the largest professional group (32.20%), followed by fisheries engineers (28.81%) and food engineers (19.49%). The remaining participants included academic staff and fisheries association managers. Notably, the majority of participants (71.43%) possessed 1-5 years of experience in the fisheries and aquaculture sector (Figure 2).

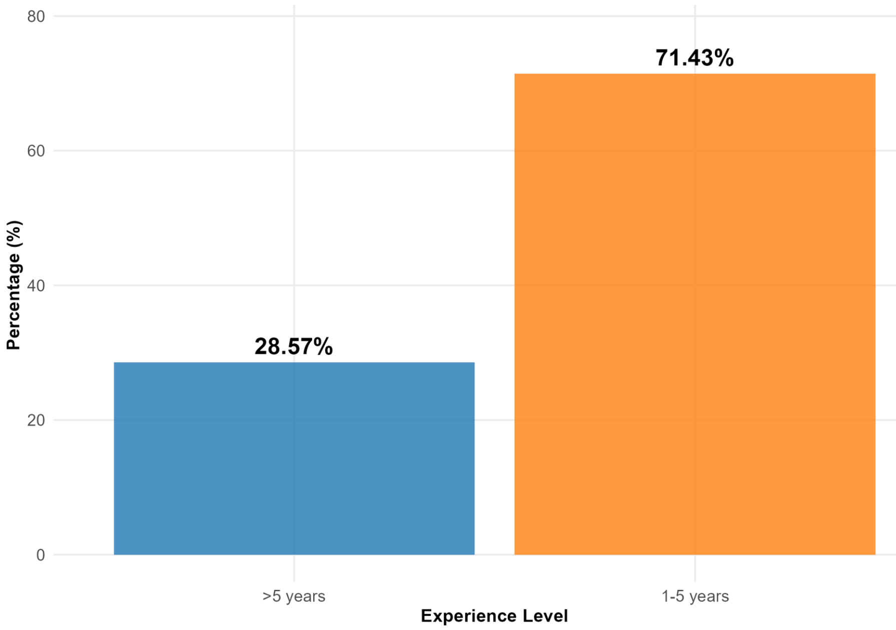

Figure 2. Participant Familiarity with the Pet Food Industry and Fishery Discards.

Module design

The training modules were designed to be flexible and customizable, developed in direct response to the evaluated needs and existing skill levels of the target participants. The instructional design was guided by the principle of constructive alignment, ensuring that all teaching activities and assessments were directly linked to the intended learning outcomes. Key considerations included establishing measurable and attainable learning objectives for each module, often structured around a pyramidal theory of knowledge such as Bloom's taxonomy (Blook et al., 1956). The design process focused on determining the specific learning activities, materials, and support required for trainees to achieve these outcomes. Furthermore, it incorporated strategies for effectively evaluating whether the students had met the learning goals, thereby ensuring the module's overall coherence and educational efficacy. This approach was tailored to be user-friendly and particularly suited for adult learners and working professionals, featuring interconnected modules, targeted materials, and continued guidance.

FINDINGS

The project's workshops and subsequent survey garnered participation from 267 individuals across several countries, including Turkey (148 participants), Lithuania (36), Croatia (33), Iceland (29), and Norway (21). The professional composition of the respondents was predominantly veterinarians (32.20%), followed by fisheries engineers (28.81%) and food engineers (19.49%).
The findings revealed significant knowledge gaps among the participants concerning the core topics of the MARIPET project (Figure 3). A substantial majority of respondents reported knowing little to nothing about the pet food industry and fishery discards, with many unable to define what constitutes discarded fish. This lack of awareness extended to more specific areas: over 80% of participants had limited or no understanding of the critical biosafety, hygiene, and EU legislation governing the processing of discarded fish and end products (Jedrejek et al., 2016).

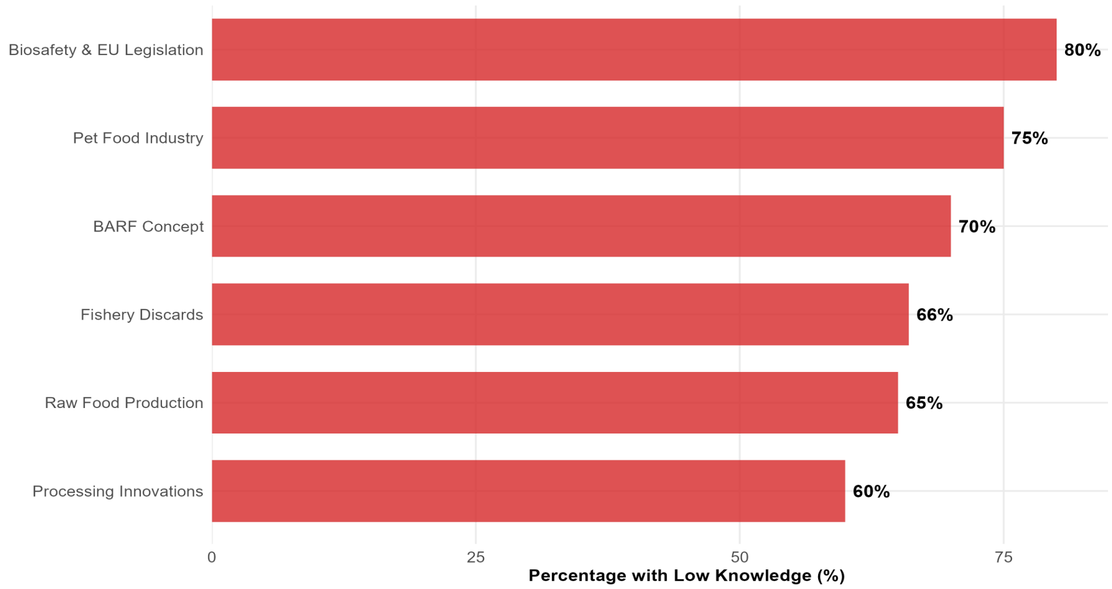

Figure 3. Understanding of Biosafety, Hygiene, and EU Legislation Related to Discard Processing.

Similarly, familiarity with Biologically Approved Raw Food (BARF) was low, although 40% of respondents believed that raw feeding is beneficial for the health of cats and dogs (Figure 4).

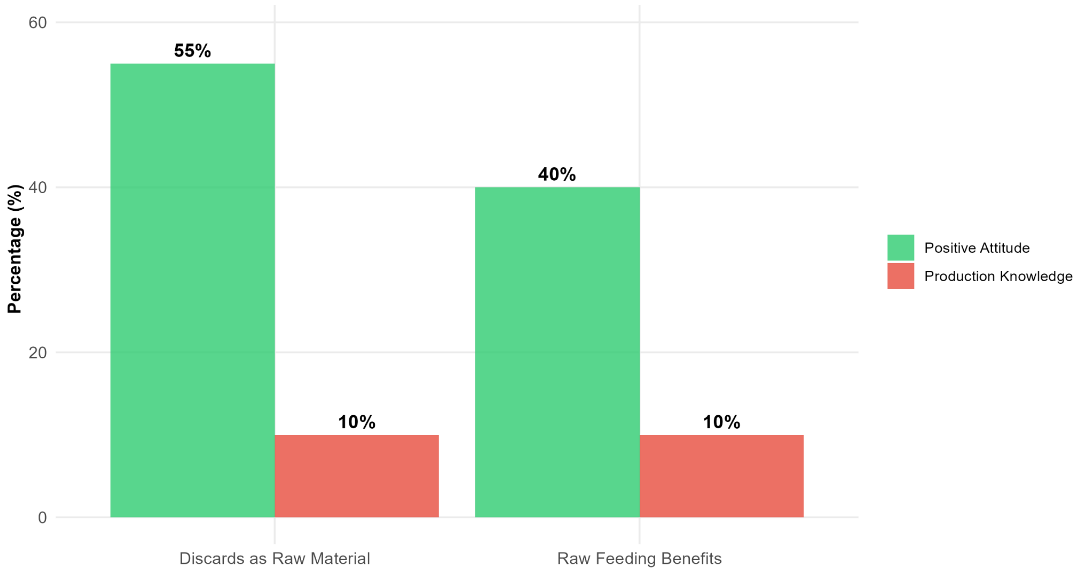

Figure 4. Participant Awareness of BARF and Perceived Health Benefits for Pets.

Despite this knowledge deficit, the data indicates a strong appetite for learning. More than half of the respondents agreed that discarded fish could be utilized as a raw material in pet food production, and a majority expressed a preference for gaining advanced knowledge on the subject (Figure 5).

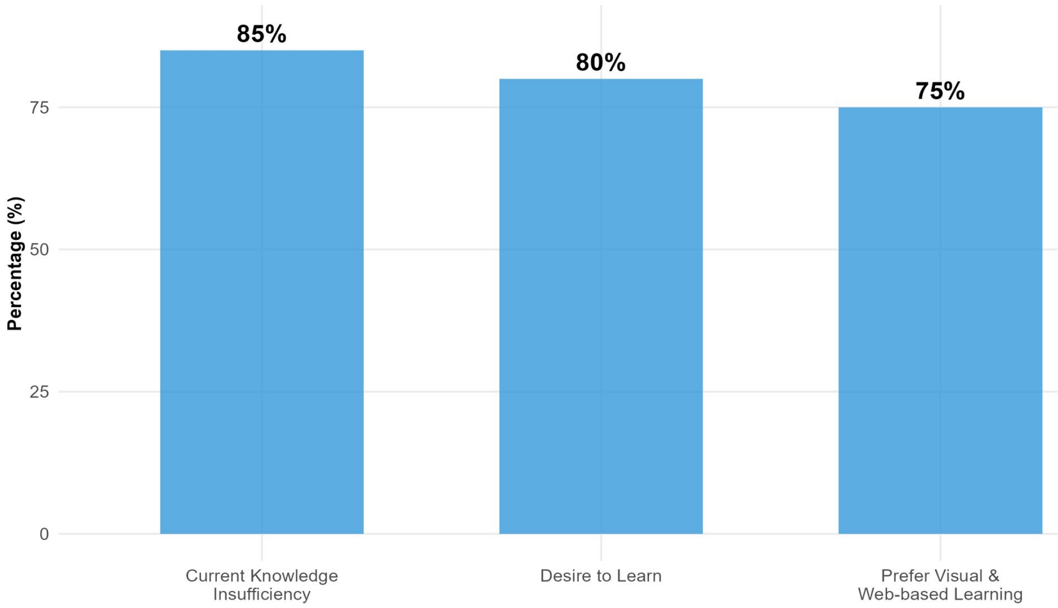

Figure 5. Perceived Viability of Using Discarded Fish as Raw Material for Pet Food.

The most encouraging finding was the participants' clear preference for the mode of education; an overwhelming number indicated a desire to learn about raw food production using fishery discards through visual and web-based educational formats (Figure 6).

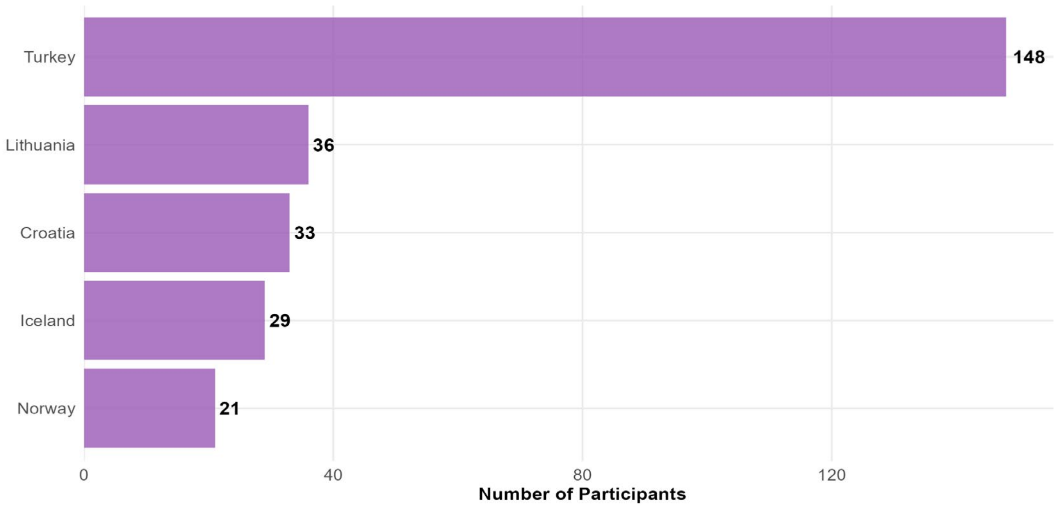

Figure 6. Preferred Modalities for Training on Fishery Discard Utilization.

This underscores a clear opportunity for the developed curriculum to meet a defined and urgent need for specialized training.

DISCUSSION AND CONCLUSION

This study underscores that fishery discards represent a critical triad of challenges: a significant waste of resources, a substantial economic loss, and a serious ecological issue (Fotodimas et al., 2025). A primary outcome of the MARIPET project has been to elevate awareness of this problem among sectoral professionals and to motivate efforts toward its reduction. The research is predicated on the understanding that fish, whether destined for human consumption or otherwise discarded, retain high nutritional value. This principle led to the key conclusion that discarded fish can be effectively valorised as a viable ingredient in the pet food industry (Castrica et al., 2018).

The second major achievement was the development and delivery of a specialized training module, which demonstrated the practical steps and procedures for transforming discards into pet food, specifically Biologically Approved Raw Food (BARF). This program, presented to a chain of professionals from fishermen to pet food producers, was complemented by an exhibition of a sustainable economic business model. Consequently, the project's ambition extended beyond mere training; it aimed to establish a sustainable and circular transformation chain that serves as an innovative economic policy for both the fisheries and pet food sectors.

Furthermore, the project successfully created a shared platform for experts, trainees, and industry representatives. The survey of 267 participants yielded critical insights that directly informed the curriculum's design. The findings confirmed a widespread lack of knowledge about the pet food industry, fishery discards, and BARF production among key professionals, including veterinarians and engineers. However, they also revealed a strong consensus on the potential of using discards as raw material and an overwhelming desire for visual and web-based education on the topic.

In conclusion, the MARIPET project successfully identifies a viable pathway to mitigate an environmental problem while creating economic opportunity. By aligning a clear market need with a structured educational initiative, it lays the groundwork for a new, sustainable supply chain that benefits marine ecosystems, the fishing industry, and the pet food market alike. The significant knowledge gaps identified highlight the necessity of the developed curriculum, while the participants' eagerness to learn confirms its potential for impactful implementation.

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Curriculum Development for MakerLabs: A Literature Review

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ABSTRACT

Since 2005, the maker movement, which has spread globally, has contributed to education by encouraging creativity, problem solving, and entrepreneurship through hands-on, technology-supported applications. In this context, MakerLabs, which are education-focused maker environments, are gaining more and more ground in the curriculum thanks to their student-centred, project-based learning structure. In this study, a literature review was conducted to examine the place of makerlabs in higher education and to investigate the relationship between makerlabs and engineering systems, design thinking, entrepreneurship, and mentoring. The research covers the period between 2003 and 2025. It focused on the relationship between the seven identified keywords (makerlab, engineering design systems, robotics, STEM, design thinking, entrepreneurship, and mentor support) and makerlab and education. Two thousand articles containing the identified keywords were selected, and the 46 most relevant articles were analysed. MakerLabs enable students to develop 21st-century skills such as critical thinking, collaboration, and innovation. They also provide students with the opportunity to apply theoretical knowledge in real-world contexts. Additionally, they prepare students for entrepreneurship, encourage interdisciplinary approaches, and help them develop their own skills. However, issues such as sustainability, infrastructure deficiencies, teacher competencies, and inequalities hinder their wider adoption. The results indicate that MakerLabs can be an effective learning environment when supported by a good curriculum and sufficient resources. More empirical research is recommended to determine learning outcomes and optimize the use of MakerLab applications in universities.

Keywords: *Makerlab, curricula, engineering design systems, robotics, technology.*

INTRODUCTION

The maker movement, initiated by Dougherty in 2005 with the publication of Make magazine, promotes activities integrated with technology based on the concept of “do it yourself” or “do it together with others” (Peppler & Bender, 2013; Schrock, 2014; Sönmez & Şahinkayası, 2021). Suitable for constructivist learning, this movement enables individuals to take an active role in their own learning while also promoting interdisciplinary thinking (Sönmez & Şahinkayası, 2021). In Turkey, this movement gained momentum after Dougherty's visit to the country in 2013, and more than 50 maker spaces have been opened (Şahin & Tosun, 2018).

While schools are more effective venues for nurturing creatives than museums and after-school programs, they are not considered sufficiently effective due to material shortages and curriculum density. However, curricula specifically designed for creative environments focus on helping students apply their existing knowledge, thereby increasing motivation and improving the quality of learning (Dougherty, 2012). Creative workshops, which are interdisciplinary environments, support student-centred, project-based learning by encouraging the use of educational technologies, creativity, and collaboration (Davidson & Price, 2018; Smith & Johnson, 2020; Park et al., 2023; Sönmez & Şahinkayası, 2021).

Empirical studies conducted in maker workshops show positive results related to learning in these areas: students and parents reported increased active learning at the ULUTEK Maker Children's Workshop (Özünlü & Özdilek, 2018); another study examined a maker model that showed it developed the inquiry and creativity skills of BİLSEM students (İnan, 2019); at the same time, maker projects involving middle school and university students were found to be encouraging in acquiring a maker identity at an early age (Ünal et al., 2021). In another study, teachers expressed the benefits of maker workshops in terms of creativity and production, while emphasizing the need for resources and educational expertise (Hamurcu, 2023). Furthermore, while a strong potential was seen in design skill workshops, it was noted that sustainability and support improvements were required (Mısırlı, 2023). For school administrators, maker workshops yielded positive results in terms of creativity and school participation, while material shortages and teacher competencies remained a source of concern (Yavuz & Ulutaş, 2023). Overall, existing research suggests that maker workshops and curricula can enhance university students' 21st-century skills, including creativity, problem solving, and collaboration, though further studies are needed to clarify learning outcomes and processes (Hira & Hynes, 2018; Sheridan et al., 2014; Vongkulluksn et al., 2018; Tomko et al., 2017).

In this context, this study includes a comprehensive review of the existing literature on maker workshops, project-based learning, and the integration of educational technologies. While previous research has shown that maker environments encourage entrepreneurship, creativity, and problem solving, it highlights a significant gap in how structured curricula can systematically support these outcomes in higher education.

METHODOLOGY

This study's literature review was conducted to analyse the concept of makerlab and investigate recent developments in the fields of makerlab and education. The purpose of the literature review is to gather sufficient information about a concept and understand the existing literature before further conceptualization (Arshed & Dansen, 2015). The search covered the period between 2003 and 2025. Seven keywords identified by the researchers (makerlab, engineering design systems, robotics, STEM, design thinking, entrepreneurship, and mentor support) were used, focusing primarily on the relationship between makerlabs and education. Titles were scanned, and articles related to makerlabs and education were selected for more detailed examination. Subsequently, 2,000 articles containing the identified keywords were selected. After reviewing the abstracts of the articles, 46 articles that were most relevant were analysed.

RESULTS

Definition and History of the Maker Movement

With today's rapidly and unpredictably changing technologies, educational environments are also influenced by these developments. As technology is integrated into education, technology-oriented productivity and approaches that foster students' creativity in such environments gain importance. In this context, the maker movement has been spreading rapidly in Turkey and around the world (Akıncı & Tüzün, 2016).

First launched in 2005 by Dale Dougherty to spread the maker movement, the magazine 'Make' popularized the maker movement among the masses. It encompasses activities that involve the relationship between technology and the 'do it yourself' or 'do it with others' mindset (Peppler and Bender, 2013; Schrock, 2014; Sönmez and Şahinkayası, 2021). The maker movement is defined as a craft movement that involves a connection with materials through hobbies such as crafts, robotics, digital fabrication, mechanical repair, and woodworking, and, unlike existing crafts, involves a new way of making, creating, and designing. Based on this, it becomes clear that the maker movement encompasses the making of almost everything (Peppler and Bender, 2013; Schrock, 2014).

One of the world's first maker production areas, Creation Workshops, opened in the United States in 2006. After the opening of the first maker production area, the number of maker areas, which significantly contributed to students transforming the knowledge they learned at school into tangible products, increased significantly over time (Şahin & Tosun, 2018). The maker movement has been actively present in Turkey for many years. Vecihi Hürkuş, who produced Turkey's first domestic aircraft, was one of the first Turkish makers; another pioneering maker was industrialist Mennan Aksoy. Faced with the high cost of imported spare parts hindering production, Aksoy implemented a TÜBİTAK project and, with the machine he produced with his team, contributed to Turkey becoming competitive in the global market. The real momentum for the maker movement in Turkey came after its founder, Dougherty, visited Turkey in 2013 to introduce the movement and meet with Turkish makers. Before the meeting, it was emphasized that there were no maker production areas in Turkey; after visiting universities and high schools, it was concluded that the movement needed to be spread, and more than 50 areas were opened in a short time (Şahin & Tosun, 2018). Although the number of maker workshops in Turkey is still low compared to the rest of the world, the number of maker workshops in Turkey began to increase rapidly with the opening of Istanbul MakerLab in 2014 (Akıncı & Tüzün, 2016; Kaygısız, 2021; Sönmez & Şahinkayası, 2021). Turkish maker spaces offer tools and opportunities for computer software, 3D printing, woodworking, programming, chemistry, and mobile applications (Akıncı & Tüzün, 2016). Thanks to the development of the maker movement over time, the movement's basic components and areas of application have been systematically defined.

Core Components of the Maker Movement

The Maker movement is a universal trend that encourages individuals to use technology as a tool to create and produce their own creative products. This movement, which stems from the idea that people can showcase the products they create using technology, aims not only to equip people with technological skills but also to provide them with 21st-century skills such as problem-solving, critical thinking, collaboration, and entrepreneurship. This movement has spread rapidly worldwide (Şahin & Tosun, 2018). The maker movement aligns with a constructivist approach based on learning by doing and experiencing. Maker applications enable individuals to become the agents of their own learning while also supporting interdisciplinary thinking and production (Sönmez & Şahinkayası, 2021).

One area where the maker movement intersects with education is coding and robotics. Coding is not only a digital skill but also a way of solving problems. Robotics projects teach individuals systematic thinking, algorithm creation, and feedback skills. Components such as electronic circuits, sensors, and motors used in robotics and coding applications in maker spaces provide insight into real-world engineering applications. They also develop learners' teamwork and problem-solving skills. Beyond computer science, the applicability of coding across multiple disciplines makes it an important component of the maker movement (Sönmez & Şahinkayası, 2021). Sharing products created individually or collaboratively is also an important part of the movement (Akıncı & Tüzün, 2016). The maker movement encompasses not only individual production but also community-based learning. Maker spaces are dynamic environments where people share their experiences, solve problems together, and learn from each other. The use of open-source philosophy facilitates access to information and accelerates learning (Anderson, 2012). Maker-based activities, especially Maker Faire, spread this culture and bring together individuals of different ages and disciplines.

The term “maker movement” was proposed by Dougherty (2012) to describe the activities of those interested in technology components such as 3D printing, Artificial Intelligence (AI), the Internet of Things (IoT), Computer-Aided Design (CAD), and Computer Numerical Control (CNC) (Tabarés & Boni, 2023). IoT essentially encompasses all objects that can connect to the Internet. Examples include home security, lighting, and air quality control systems. The use of IoT in the maker movement enables individuals to develop product models by teaching them how to connect objects, digitizing objects and encouraging creativity while bringing the movement into new fields of work through product diversity (Shu & Huang, 2021).

One of the fundamental components of the movement is digital production tools. 3D printers, laser cutters, CNC machines, and microcontrollers such as Arduino and Raspberry Pi facilitate easy product design. Products created in maker spaces can include model cars made with electronic circuits or decorative objects printed on 3D printers, among others; all of these embody the maker spirit (Sönmez & Şahinkayası, 2021). This product diversity demonstrates not only individual creativity but also the importance of the fundamental components and physical environments that support the movement. The application of components in various production environments has laid the foundation for different types of maker spaces. Understanding these fundamental components is crucial to understanding how the maker movement has taken shape through physical environments and workshop types. Important physical spaces include maker spaces, fab labs, and hacker spaces. These environments provide the digital tools necessary for project development while offering interactive and innovative learning environments. In this way, they differentiate themselves from traditional classrooms and support student-centred education (Halverson & Sheridan, 2014).

The maker movement, which enables active participation in production, transforms individuals from mere consumers into transformers of technology. The digital production tools, collaborative environments, coding skills, and creative production processes that form the core components of the movement equip individuals with 21st-century skills. As a result, maker applications integrated into educational environments increase motivation and promote creative solutions for a sustainable future by enabling active learning.

Maker Spaces and Types

Creative spaces where creators learn to use materials and tools and come together to produce according to new projects are called Creative Laboratories (MakerLab), production areas (Makerspace), hacker spaces (Hackerspace), and digital production laboratories (FabLab) (Kocaman-Karoğlu et al., 2020; Öztürk, 2016). Although creative spaces are generally used for the same purpose, they have different areas of focus (Öztürk, 2016). Through these different focal points, creative spaces integrate into various cultures, regions, and contexts and can be used effectively in different learning environments (Demir & Güneş, 2020).

By focus: FabLabs aim to produce technology-supported physical and digital products and operate within a specific standard. Hacker spaces provide information sharing and focus on software, hardware, and security for technology enthusiasts, hackers, and programmers. The main difference between maker spaces and MakerLabs is that maker spaces are generally production-oriented, while MakerLabs are education-oriented. While Makerspaces can be established in libraries, workshops, and schools, MakerLabs are only established in educational institutions. As educational reflections of the movement, MakerLabs facilitate interdisciplinary learning, encourage the active use of knowledge and production, and provide tools and opportunities for hands-on learning and prototyping (NMC Horizon, 2017).

Fairs organized to showcase products designed through maker activities are called "Maker Faire." These fairs, which have no age barrier and are low-cost or free, attract adults while inspiring students, the productive individuals of the future (Kaygısız, 2021). They also bring together makers from different disciplines who rarely come together in daily life. Projects in the fields of art, science, craft, and engineering, and the makers who carry them out, come together at a common point and encourage interdisciplinary interaction and knowledge sharing (Dougherty, 2012).

The Role of the Maker Movement in Education

The maker movement is a creative and innovative approach that drives change and transformation in education. This movement is led by expert makers who bring innovations to their communities, adapt them to local needs and interests, and provide active learning environments for young makers (Peppler & Bender, 2013).

Maker education is provided not only to students but to anyone over the age of three (Sönmez & Şahinkayası, 2021). Regardless of one's profession, activities such as cooking, gardening, or knitting are sufficient for a person to be considered a "maker." This movement originated from people who see objects not merely as consumers but as something that connects them to real life. True makers should adopt an approach similar to that of pioneers in the computer industry, who conduct experimental work with technology and maintain a constant curiosity about the unknown (Dougherty, 2012).

Due to its multidisciplinary nature, the maker movement cannot be clearly defined across different fields. From an educational perspective, it is seen as a tool compatible with constructivism, while from an economic perspective, it is valued as a process that contributes to entrepreneurship (Demir & Güneş, 2020). This is because the maker movement provides materials for entrepreneurs to produce products in the entrepreneurial process (Ünal et al., 2024). Maker education, which develops project-based and design-oriented thinking skills, enables students to bring their own projects to life while increasing their curiosity and interest in science (Sönmez & Şahinkayası, 2021).

Maker spaces come in two types: educational and non-educational. Non-educational maker spaces are often used as hobby spaces for adults. Educational maker spaces, on the other hand, are active learning environments where learning occurs through doing and creating. Because collaborative work is supported in addition to individual work, these spaces also develop students' critical thinking skills (Sönmez & Şahinkayası, 2021).

Experts developing programs for educational makerspaces must possess a maker mindset. Programs should be tailored to specific needs that can only be accurately identified by experts with a maker perspective. Activities developed by individuals lacking a maker mindset are inadequate for use in makerspaces. Maker programs also require a structured workflow. However, these plans should be designed in a way that encourages trial and error without restricting students' creativity. Programs should not be too short; their duration should allow students to feel a sense of belonging in the process and to progress at their own pace.

Integrating maker education into schools, where students spend most of their day, would be even more effective than integrating it into science museums or after-school programs. However, students may become bored or feel inadequate in a school-integrated program. Therefore, program designers should focus not on assessing future generations of makers, but on teaching them how to apply their existing knowledge. As students learn what they can do and create new products, they discover their potential, which increases their motivation and the quality of their learning (Dougherty, 2012).

By the end of a well-planned maker program, students should have experienced meaningful experiences (Akıncı & Tüzün, 2016). Furthermore, by the end of the program, students should possess 21st-century skills (scientific, financial, and cultural literacy; problem-solving and critical thinking; collaboration; entrepreneurship; data analysis; effective oral and written communication; curiosity and imagination). They should take responsibility throughout production, actively use information and communication technologies, and develop new ideas. Expert makers, the ideal implementers of programs for school-aged children, should act not only as transmitters of ready-made knowledge but also as guides preparing students for the future. In educational maker spaces, learners, not teachers, are responsible for the learning they learn (Kaygısız, 2021; Öztürk, 2016). This transformative effect in educational environments is further enriched by the opportunities provided by educational technologies. This approach encourages creativity while combining modern educational technologies to provide stronger and more interactive learning environments.

Integration with Educational Technologies

The multidisciplinary maker movement aims to facilitate the learning of maker students (Davidson and Price, 2018). Considering how integrated younger generations are with technology, the most effective way to use technology in production is through maker and STEM education, which fosters interdisciplinary collaboration (Kaygısız, 2021). In recent years, the maker movement has made significant advances in education through STEM and the arts, streamlining learning processes and content (Peppler and Bender, 2013). The need for maker and STEM education stems from the rapid digitalization of industry (Industry 4.0) and from countries seeking economic differentiation by adapting to digitalization and remaining competitive. In this context, this type of education is seen as an effective way to implement STEM, which focuses on problem-solving, teamwork, knowledge creation and sharing, networking, experimentation, and prototyping.

A maker culture contributes to STEM by encouraging collaboration across disciplines and bringing them closer together. Technologies such as robotics, 3D printing, artificial intelligence, cybersecurity, and robotics encompass technical skills that can be developed using STEM. The increasing demand for STEM is due to advancements in teaching methods and the workforce demand generated by a digitalizing industry (Tabarés & Boni, 2023). Schools need STEM-based maker learning, which provides ample opportunities to experiment with the integration of interdisciplinary subjects like STEM and create products accordingly (Shu & Huang, 2021).

The maker movement also impacts global economies. Throughout the maker movement, groups from diverse socioeconomic backgrounds, as part of society, come together for different purposes, creating new businesses and employment. Meeting local needs through this type of employment reduces unemployment (Çeliksap, 2017). At the same time, students realize that by producing products, they not only become customers of commercial companies but also establish companies as producers (Öztürk et al., 2017). Anderson (2012) argued that the maker movement is a new industrial revolution (Çeliksap, 2017).

Accordingly, maker workshops are vital learning environments for changing traditional teaching methods. When combined with educational technologies, these workshops become more dynamic and interactive. Tools such as 3D printers and robotics kits offer students opportunities to create concrete projects. Maker environments allow students to enrich their learning processes with technology and apply their ideas in the real world (Papadopoulos, 2021). Educational technologies in these workshops allow students to interact with new tools and personalize learning as they design their projects. Maker workshops also enable students to develop teamwork skills in socially interactive spaces (Smith & Johnson, 2020). Project-based learning in these spaces strengthens teamwork skills by providing an interactive environment that fosters creative thinking, engineering skills, and collaborative learning (Smith & Johnson, 2020). From these perspectives, maker workshops integrated with educational technologies play a crucial role in helping students acquire engineering systems and design processes.

Engineering Systems and Design Processes

It is essential to examine the effects of maker workshops from various perspectives, including engineering systems, design thinking, entrepreneurship, and mentorship. Teaching engineering systems in maker workshops provides learners with theoretical knowledge, as well as crucial practical skills. Engineering design processes involve steps such as problem-solving, prototyping, testing, and iteration. Maker workshops enable students to comprehend these processes and create solutions using engineering systems.

In MakerLab environments, engineering principles are taught within real-world contexts, and students apply what they learn through projects they design and develop (Becker & Park, 2017). Thanks to technological tools such as 3D printers and Arduino kits, creative ideas become tangible artifacts. Students test engineering systems using various tools and actively engage in revising and improving their projects based on feedback. Maker workshops also offer collaborative learning opportunities, enhancing group work and interactive learning (Blikstein, 2013). Thus, engineering systems arise from the combination of design processes, technological tools, and engineering principles.

Maker workshops provide suitable environments to learn and experience hands-on applications of engineering systems. Students who experience engineering design, product development, and testing gain opportunities to engage in projects and understand design thinking and its stages (Yang & Liu, 2022). This experience has been shown to improve teamwork, leadership, and communication skills (Zhao & Zhang, 2021).

Considering communication skills, MakerLabs are crucial venues for teaching engineering systems in interactive settings. They enable the integration of engineering experiences into daily life while facilitating the practical use of theory and promoting lasting learning. Projects carried out in MakerLabs help translate engineering systems from purely academic knowledge to practical, workplace-applicable skills and contribute to students' career development (Li & Wang, 2022). As many studies indicate, hands-on activities are beneficial for developing new approaches to problems and technical skills (Wang & Zhang, 2021).

In recent years, maker workshops have become an essential learning environment that supports project-based learning within a learner-centred approach. They aim to equip students with critical skills such as creative thinking, engineering abilities, collaboration and teamwork, and problem-solving. The integration of educational technologies increases interactivity and supports more efficient learning. Additionally, elements such as engineering systems, design thinking, entrepreneurship, and mentorship play key roles in the success of maker workshops (Park et al., 2023).

Among these elements, design thinking stands out. Design thinking supports creative and innovative problem-solving processes and plays a significant role in the success of maker workshops. It enables students to develop creative solutions to everyday problems. The approach includes empathizing, defining the problem, generating solutions, developing products, and testing them (Brown & Ghosh, 2020). It also helps students progress through iteration and feedback (Del Moral Pérez et al., 2025). These processes and experiences enable students to develop different perspectives and innovation-oriented solutions. Especially in engineering and technology projects, design thinking involves ideation, prototyping, testing, and receiving feedback (Smyth et al., 2020). Students can iteratively develop these processes and treat failures as learning tools through new trials guided by feedback. The combination with educational technologies makes learning experiences more accessible and interactive (Miller & Young, 2021).

Mentorship and Guidance Practices

Beyond imparting engineering skills, an important factor that increases the effectiveness of learning in maker workshops is mentorship and guidance. Mentors guide students and support the development of their projects. Especially in complex engineering and entrepreneurship projects, mentors provide technical support and practical, actionable knowledge that helps students succeed (Hwang & Lee, 2021).

Mentorship helps students implement projects more quickly, while advancing their skills. By guiding project development, mentors help students use their potential more effectively. This support plays a critical role in generating innovative solutions and, throughout the process, helps students think like engineers while developing entrepreneurial skills (Rodriguez & Lee, 2021). Mentorship also helps students overcome existing or potential obstacles, and by providing support in challenging areas, improves project quality (Liu et al., 2020). In short, mentors play a decisive role not only in developing technical skills but also in building entrepreneurial competencies.

Maker Workshops and Entrepreneurship Education

Maker workshops can be seen as an important part of the startup ecosystem. In these environments, students develop creative projects that can be transformed into business ideas ready for real-world implementation. Maker culture enables entrepreneurial students to rapidly plan and test prototypes, and build products, providing a learning experience that prepares them for successful ventures (Anderson, 2012). Maker workshops offer mentorship and networking opportunities to develop entrepreneurial skills and help students explore their passions and choose career fields they can experience firsthand (Next Generation Learning Challenges, 2022). Mentors help students develop ideas, and drawing on real-world experience, provide information about career opportunities. Such support motivates students to improve their success while developing risk-taking and innovative thinking (Anderson, 2012; Next Generation Learning Challenges, 2022). Hence, mentorship is critical for efficient learning in maker workshops. By identifying strengths and weaknesses, mentors contribute to development and enable students to complete complex engineering projects or entrepreneurship processes with more effective solutions (Pittaway & Cope, 2007).

By combining entrepreneurial spirit and mentorship, each element enriches learning, helping students develop both theoretical knowledge and practical skills. These spaces have great potential in STEM and entrepreneurship education and build critical skills for the future workforce. With consistent, relevant mentorship, students' self-confidence grows. Participation in learning environments such as maker workshops helps students develop entrepreneurial skills (Kidpreneurs, 2024).

Entrepreneurship ensures that students do not only develop technological abilities but also acquire commercial thinking skills. Maker culture encourages students to bring projects to market, develop business ideas, and apply them in the business world. They learn to take risks and develop entrepreneurial skills during commercialization (Choi & Lee, 2022). Implementing innovative projects in maker workshops increases student motivation (Tiago et al., 2015). Although maker workshops offer important opportunities for entrepreneurship education, certain limitations in practice can prevent this potential from being fully realized.

Limitations of the Maker Movement

Maker workshops - experience-based learning environments aimed at strengthening creativity, design, problem-solving, collaboration, and entrepreneurship - occupy an important place in contemporary education. However, due to certain practical limitations, their potential cannot be implemented equally across institutions. The main constraints on popularizing the movement are infrastructure deficiencies, teacher competencies, sustainability issues, and technological inequalities.

Infrastructure shortcomings are among the most apparent obstacles to establishing and sustaining maker workshops. Digital fabrication tools, such as 3D printers, Arduino kits, and laser cutters, are costly and require technical knowledge and maintenance (Blikstein, 2013; Ünal, Özdemir, & Çetinkaya, 2024). This complicates establishing and operating such workshops, especially in rural schools and universities with limited budgets.

For the healthy integration of maker culture into education, teachers need to adopt new roles and approaches. Many teachers currently lack adequate knowledge and experience in design thinking, project-based learning, and digital fabrication - the foundations of the maker movement (Davidson & Price, 2018; Sönmez & Şahinkayası, 2021). Therefore, teacher education programs should include content on maker pedagogy.

Another limitation concerns sustainability. Many workshops are established through short-term projects or grants; when such support ends, they cease to function. The lack of structural planning for continuity prevents maker culture from becoming permanent in education (Demir & Güneş, 2020). Maker workshops should be institutionally owned and reinforced through partnerships with local actors. Inequalities in access to technological infrastructure and digital tools also threaten the inclusive nature of maker workshops. Students from lower socio-economic backgrounds or rural areas often cannot benefit sufficiently from maker opportunities. This harms educational equity and deepens the digital divide (Hira & Hynes, 2018; Andrews et al., 2021).

Considering these limitations, it is clear that for maker workshops to create an effective transformation in education, they must be supported not only pedagogically but also economically, technically, and structurally. Educational programs to be developed should include sustainable and inclusive models that account for such barriers. These constraints highlight both the strengths and the under-addressed areas in the literature on maker workshops, making it necessary to examine trends and gaps more closely.

CONCLUSION

A review of the literature reveals that maker workshops provide an ideal environment for students to actively participate in design-focused thinking processes, empathize with users, and engage in product development and prototype testing. Similarly, studies by Carbonell et al. clearly demonstrate the positive impact of using maker workshops on students' design and design self-efficacy and innovation self-efficacy (Carbonell et al., 2019). Another study on maker workshops has also revealed that students who frequently use the opportunities offered by maker workshops have higher levels of self-confidence in the skills that this field aims to support. Based on this, it can be seen that applied learning environments can increase students' cognitive abilities and self-efficacy (Lagoudas et al., 2016).

Maker workshops enable students to develop critical thinking, problem-solving, and collaboration skills while bringing their ideas to life (Sheridan et al., 2014). The collaborative learning experience is crucial for developing an entrepreneurial mindset, as it encourages social responsibility and innovation by supporting students in increasing their interaction with peers and society (Lim, 2021). Maker workshops aim to develop creativity, problem solving, and other 21st-century skills that are critical for success in today's rapidly changing business world by offering students opportunities to design and build with various technologies (Soomro et al., 2023; Tomko et al., 2017). The work carried out in maker workshops allows students to apply theoretical concepts in real-world contexts and enhances their motivation and understanding of the entrepreneurial process, thereby encouraging students' social responsibility, creativity, and innovation skills and further enriching the learning experience (Farhangmehr et al., 2016; Hamidi & Baljko, 2015; O'Brien & Hamburg, 2019; Rodrigues, 2023).

The current literature suggests that maker workshops may have a positive impact on the development of university students' 21st-century skills and cognitive skills. This literature review, which examines maker workshops in an educational context, reveals that maker workshops have the potential to positively impact students' 21st-century and cognitive skills and that they develop creativity, problem-solving, collaboration, and other critical abilities. However, the specific learning outcomes and processes associated with maker workshops remain largely unexplored, and further research is needed to fully understand the learning outcomes and processes (Hira & Hynes, 2018; Sheridan et al., 2014; Vongkulluksn et al., 2018; Tomko et al., 2017).

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