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Technology-Enabled Learning for Green and Sustainable Entrepreneurship Education

Adina Cocu [1], Emilia Pecheanu [1,*], Ioan Susnea [1,*], Sandra Dingli [2], Adrian Istrate [1] and Cornelia Tudorie [1]

[1] Department of Computers and Information Technology, Dunarea de Jos University of Galati, 800210 Galaţi, Romania; adina.cocu@ugal.ro (A.C.); adrian.istrate@ugal.ro (A.I.); cornelia.tuodrie@ugal.ro (C.T.)

[2] The Edward de Bono Institute for Creative Thinking and Innovation, University of Malta, 2080 Msida, Malta; sandra.m.dingli@um.edu.mt

* Correspondence: emilia.pecheanu@ugal.ro (E.P.); ioan.susnea@ugal.ro (I.S.)

Abstract: (1) Background and objectives: Global crises such as climate change, pandemics, and resource depletion present unprecedented challenges that require coordinated and innovative responses. This study advocates for a bottom-up strategy by proposing and developing tools that empower individuals and organizations to embrace green and sustainable entrepreneurship, fostering localized solutions with global impact. In this context, the research explored the integration of technology-enabled entrepreneurship education (EE) into engineering curricula, with a focus on sustainable and green entrepreneurship. Leveraging insights from European projects, the research developed a cloud-based entrepreneurship educational system featuring three e-learning platforms. Particularly, one e-learning platform was specifically designed to support green and sustainable entrepreneurship education. (2) Methods: the study involved literature reviews, stakeholder surveys, interviews with green entrepreneurs, and iterative platform design. (3) Results: Key outcomes of the research include a methodology for designing pedagogical strategies and learning content for green and sustainable EE. Additionally, digital tools such as the green business innovation canvas, TRIZ-inspired matrices, and AI-driven recommendation systems were created to equip learners with the skills to develop sustainable business models. (4) Originality: The study's novelty lies in its integration of advanced digital tools with original pedagogical strategies, providing a scalable framework for incorporating sustainability into entrepreneurship education. These findings have practical implications for educators and policymakers working to promote eco-friendly business practices. Future research should investigate the scalability of these tools across diverse educational contexts and evaluate their long-term impact on fostering sustainable entrepreneurial mindsets.

Keywords: green and sustainable entrepreneurship education; e-learning; conceptual learning; knowledge graphs; generative AI

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1. Introduction

1.1. Background and Objectives of the Study

Since the signing of the Kyoto Protocol and the Paris Agreement on climate change, the challenges associated with the need for sustainable development have become increasingly pressing (Brentnall & Higgins, 2024). This suggests that top-down approaches to addressing global crises are of limited effectiveness unless they are accompanied and supported by bottom-up initiatives driven by economic actors.

The bottom-up initiatives may benefit from the firsthand knowledge of the entrepreneurs and local communities of specific challenges and cultural contexts. Small-scale solutions can be tested, iterated, and improved more rapidly than large-scale policies.

Arguably, widespread education in green and sustainable entrepreneurship may be one of the most effective strategies for implementing a bottom-up approach to tackling these crises.

Entrepreneurial activities are recognized as key drivers of progress in modern society, playing a significant role in economic growth, job creation, technological innovation and in addressing societal needs.

These social trends led to a rising emphasis on delivering entrepreneurship education, (Stoica et al., 2020; Galindo & Méndez, 2014) within educational systems globally. Entrepreneurship education (EE) aims at helping individuals acquire the skills and the mindset necessary to navigate and succeed in economic and business environments, (Rideout & Gray, 2013). Furthermore, EE is believed to enhance learners' creativity and problem-solving capacities, valuable qualities across career paths in today's social and economic backgrounds.

The urgency of climate change and the outbreak of the COVID-19 pandemic shifted the focus of EE towards green and sustainable aspects (UNESCO, 2020).

The pandemic exposed vulnerabilities in the global economic systems, prompting a reevaluation of traditional business models and an increased emphasis on sustainability in business practices (Bogoslo et al., 2022).

Green entrepreneurship, which encompasses eco-friendly and sustainable business practices, emerged as a new direction for socio-economic development. Many entrepreneurs are now focusing on business projects that prioritize environmental sustainability alongside profitability. Although the interest in green entrepreneurship is growing, comprehensive frameworks and digital tools for supporting green and sustainable entrepreneurship education remain scarce.

In this context, the general objective of the present study can be formulated as follows: to develop the methodological framework for creating educational content for green and sustainable entrepreneurship, and to create a scalable digital platform capable to deliver this content to a large number of learners.

To guide the study and frame the interpretation of findings, the following research questions were formulated:

RQ1: How can digital systems and tools support traditional and innovative pedagogies in entrepreneurship education?

This question explores the capabilities and features of digital systems in enhancing EE by supporting both established and novel pedagogical approaches.

RQ2: How can the digital tools and innovative pedagogical approaches—such as conceptual learning developed in this study—contribute to green and sustainable entrepreneurship education?

This question investigates how digital interactive tools pedagogies can be created to better assist students in designing eco-friendly business projects, balancing environmental objectives with profitability, and incorporating best practices in sustainability.

RQ3: How can the digital tools and pedagogical approaches developed in this study foster students' creativity and innovation skills?

This question examines the contributions of digital interactive tools, including TRIZ-like innovation matrices and others, in supporting the development of students' creative and innovative problem-solving skills.

RQ4: How can generative AI enhance the creation of effective digital content for technology-driven learning in green entrepreneurship?

This question examines the role and effectiveness of generative AI in structuring and organizing raw data, facilitating data integration and retrieval, delivering personalized recommendations, and supporting students in understanding complex concepts and developing innovative solutions in green entrepreneurship.

1.2. Research Gap and Novelty

Despite the growing emphasis on entrepreneurship education (EE) as a tool for fostering innovation and economic resilience, its integration into engineering curricula with a focus on green and sustainable practices remains underexplored.

While existing studies highlight the importance of sustainability in business education, they often lack practical frameworks and digital tools to effectively deliver these concepts. Moreover, few studies systematically investigated how cutting-edge technologies can enhance the teaching and learning of sustainable entrepreneurship.

Unlike previous studies that primarily focus on traditional EE methods, (Pittaway & Cope, 2007; Lackéus, 2015), this study introduces novel digital tools and pedagogical approaches tailored to green entrepreneurship. This approach is supported by recent advancements in IT technologies (Edge et al., 2024).

In this sense, the study fills the research gaps by:

- Developing a cloud-based educational system that integrates three e-learning platforms tailored for sustainable entrepreneurship education.
- Providing practical insights through field research, including interviews with entrepreneurs engaged in green practices, and creating a data repository of real-world case studies to support experiential learning.
- Developing a methodology for creating digital content using raw data on green businesses gathered from real-world sources, converted into a structured computational format with the help of advanced IT technologies as generative AI.
- Incorporating innovative learning technologies, including conceptual learning frameworks, to deepen students' understanding of green business principles.
- Exploring the use of AI-driven recommendation systems to provide personalized guidance in designing sustainable business models.

By offering scalable tools and methods, this research provides an original contribution to the fields of entrepreneurship education and sustainability.

2. Brief Review of the State of the Art in Entrepreneurial Education and Technology-Enabled Learning

2.1. Literature Review Insights for Technology-Enabled Entrepreneurship Education

The design and development of our cloud-based digital system for EE has been achieved within the framework of three European projects, ProBM2, (ProBM2, 2021), EntrNET, (EntrNET, 2023), and InnoGreen, (InnoGreen, 2024). These projects aimed to enhance digital learning in the field, with a focus on green and sustainable entrepreneurship in the latest project, InnoGreen.

To support these objectives and deliver effective digital learning tools, foundational studies were conducted during the initial projects' stages. These studies included literature reviews and research to investigate the latest trends in EE. The reviews provided valuable insights, such as identifying tendencies, gaps in current practices, and novel approaches such as AI-driven tools. The review findings influenced the design strategies used in developing digital systems and tools for EE.

The literature review included studies (e.g., Giacomin et al., 2011; Katz, 2003; Lin & Sekiguchi, 2020) and reports (e.g., Kozlinska, 2011) examining the content and outcomes of EE programs across diverse educational settings. The Eurydice report, by the EACEA Agency of the European Commission (EACEA Eurydice, 2016), offered valuable insights into the current state of EE in Europe. These sources provided comprehensive analyses, highlighting both the strengths, the limitations, and areas for improvement in existing EE teaching and learning practices.

The literature review highlighted several limitations in EE, including the absence of a commonly accepted definition, clear expected outcomes, and standardized teaching methods. These remain topics of ongoing debate. Additionally, there is a shortage of specific tools for assessing learning outcomes in EE, and few educational settings incorporate practical entrepreneurial experiences as a regular part of the curriculum.

In technology-enabled EE, the literature highlights various approaches, including virtual lectures, project-based learning, and interactive simulations. These models support the experiential learning essential to entrepreneurship education (Pittaway & Cope, 2007).

Additionally, some study programs and courses incorporate gamification, peer collaboration tools, and online assessments to cultivate real-world skills and entrepreneurial mindsets, (Lackéus, 2015; Neck & Greene, 2011).

Studies on e-learning for EE emphasize the importance of experiential, as well as collaborative, and adaptive learning experiences that accommodate the different learning styles in online instructional activities (Graevenitz et al., 2010).

Recent studies highlight how generative AI can transform entrepreneurship education (Bell & Bell, 2023) and research (Ferrati et al., 2024). Generative AI supports design thinking by proposing ideas for market research, business models, and product design. This encourages students to explore and refine concepts, fostering confidence, interest, and self-efficacy in entrepreneurship education while preparing them for entrepreneurial careers. This fosters greater confidence, interest, and self-efficacy in entrepreneurship education, preparing students to address challenges and pursue entrepreneurial careers (Park & Sung, 2023).

Additionally, AI can benefit start-ups by supporting idea generation and resource optimization, empowering entrepreneurs with limited resources. Its integration into education and practice builds important skills for sustainable business opportunities.

2.2. Background Research in the Educational Context

Over the past decade, our research team participated in several EU-funded international projects aimed at developing educational content to strengthen students' transversal skills, including entrepreneurial skills, across diverse backgrounds. This content was made accessible through dedicated digital platforms. The research revealed that many transversal skills, often overlooked or insufficiently emphasized in formal education, such as creative thinking, the capacity to innovate, the ability to conceptualize information, and the capacity to incorporate contextual information in planning and decision making, are also key traits of successful entrepreneurs (Pecheanu et al., 2020).

These skills, in general, are shared by individuals who can effectively navigate the rapid technological and social changes of the socio-economic environments.

Conversely, entrepreneurial education can foster skills that are valuable not only in business, but across many professions in modern society. The entrepreneurial competencies include, among others, critical thinking, synthesizing ideas from substantial amounts of information, identifying opportunities and making quick decisions, planning, and risk management. These competencies and skills are important for success in both professional and entrepreneurial settings. However, sustaining development of these competencies through entrepreneurial education programs and courses requires a shift from narrowly focusing on business creation to fostering a comprehensive entrepreneurial mindset.

Taking into consideration all these ideas and approaches, background research was performed to complete the foundations necessary for building an EE-supporting digital environment.

This field research included surveys designed to collect feedback from stakeholders, learners, teachers, entrepreneurs, and employers, in an effort to understand their needs and preferences regarding the EE (Pecheanu et al., 2023).

Research findings show that most learners prefer practical entrepreneurial experience and favor activities involving direct interaction with entrepreneurs, such as mentoring or project collaborations.

From the learners' perspective, an effective EE program should offer content that develops a series of soft skills and transversal competencies, such as communication, creativity, critical thinking, or financial planning and management. In cases where real entrepreneurial experiences are not feasible, students emphasized the idea of having the opportunity to work with simulation environments or virtual business incubators.

Regarding the preferred method for delivering entrepreneurial education content, our students appear somehow resistant to digital technology, likely due to the survey's timing shortly after the COVID-19 pandemic, when online education was heavily utilized and linked to social isolation. Nonetheless, digital technology remains invaluable for broadening access to education.

Overall, the background research highlighted the necessity of using novel instructional methods to deliver EE content more effectively to learners. As a result, the digital content for the cloud-based platform for EE was designed for both traditional and hands-on learning experiences, such as modeling, conceptualizing, designing, planning, and lessons on how to forecast progression or identify trends in business activities.

2.3. Instructional Theories Research for Technology-Enabled Green Entrepreneurship Education

Research on instructional theories can provide a foundation for designing and developing effective technology-enabled learning systems across various domains, including (green) entrepreneurial education. These theories provide principles and approaches that can guide the creation of digital frameworks able to support users in acquiring domain-specific knowledge and skills. By integrating insights from established instructional theories, developers can design systems that effectively address user needs in terms of learning content, user engagement, and pedagogical strategies. Key instructional theories such as continuous learning theory, constructivism, behaviorism, humanistic theory, educational technology theory, and conceptual learning theory offer valuable perspectives on how technology-enabled learning systems can be structured.

Continuous learning theory highlights the need for adaptable, lifelong learning experiences supported by digital systems. To apply this theory in a green entrepreneurship e-learning course, several strategies should be implemented. Experiential learning involves hands-on projects that simulate real-world entrepreneurial activities. Reflective practices, such as self-assessment and group discussions, help students evaluate their learning and environmental impact (McLeod, 2024). An interdisciplinary approach integrates environmental science, business, and technology to provide a comprehensive understanding. Addressing real-world sustainability challenges fosters innovation and practical application of concepts (Ansar et al., 2024).

Aligned with continuous learning theory through ongoing experiential learning, interdisciplinary approaches, and sustainable challenges, the Green EE e-learning platform facilitates ongoing skill development and knowledge acquisition. It allows learners to engage with content at their own pace and revisit materials as needed.

Constructivism theory emphasizes interactive, learner-centered activities where knowledge is actively constructed through exploration and problem-solving. Its key principles include active learning, social interaction, contextual learning, and building on prior knowledge (Serhat, 2021). In a green entrepreneurship e-learning course, project-based learning can help students address real-world environmental challenges, while collaborative activities encourage teamwork and diverse perspectives (Morselli, 2018). Additionally, real-world problem-solving fosters engagement and the practical application of concepts, promoting innovation in sustainability solutions (T. Li et al., 2024).

Constructivism theory informs the design of interactive and learner-centered tools, such as ontologies, knowledge graphs, and modeling canvases within the Green EE e-learning platform. These tools enable learners to construct their understanding of green entrepreneurship through exploration and reflective problem-solving activities.

Behaviorism emphasizes the significance of reinforcement and feedback mechanisms in facilitating learning progress and maintaining user motivation. On the EE learning platform, behaviorist principles are applied through gamification and mastery learning strategies. These include the use of immediate feedback and rewards to reinforce positive learning behaviors and sustain learner engagement.

The humanistic theory of learning highlights the need to address individual learning preferences, foster self-actualization, and provide meaningful, empathetic educational experiences. This theory emphasizes personal growth, autonomy, and the alignment of learning with sustainability values.

Aligned with humanistic theory, the Green EE digital learning environment fosters independence and ethical responsibility, inspiring students to align their entrepreneurial goals with broader societal and environmental objectives.

Educational technology theory connects pedagogy and technology to enhance learning through various frameworks guiding the design, implementation, and evaluation of educational tools. Key aspects include dialogic theory, which highlights the role of dialogue and interaction in tech-enhanced learning (Wegerif & Major, 2024). Extended theories such as anchored instruction and cognitive flexibility support flexible and context-based learning, (Ouyang & Stanley, 2014). Practical applications involve developing digital curricula and using data analytics to personalize learning experiences, improving engagement and outcomes (Wegerif & Major, 2024).

Educational technology theory underscores the integration of cutting-edge digital tools, such as AI, to enhance accessibility and the effectiveness of green entrepreneurship education. Rooted in educational technology theory, this research leverages advanced tools such as generative AI and knowledge graphs to enhance the delivery of educational content, making complex concepts more accessible and fostering deeper understanding.

By leveraging these theories, technology-enabled learning systems can provide comprehensive support to users, offering tailored content, engaging activities, and effective feedback mechanisms. Together, these theories provide a robust framework for designing effective curricula and teaching methods that meet the needs of diverse learners in the context of sustainable development.

2.4. Conceptual Learning Theory and Entrepreneurship Education

Conceptual learning theory focuses on understanding concepts and their interrelationships, rather than memorizing facts or isolated pieces of information. It encourages learners to grasp overarching principles, patterns, and frameworks, enabling them to apply knowledge flexibly across various contexts. This theory is particularly relevant in education systems that aim to promote critical thinking and problem-solving skills. This pedagogy, therefore, prepares learners for real-world problem solving, emphasizing adaptive expertise over memorized responses (McLellan, 2005).

The key principles of conceptual learning theory are the following:

- Understanding over memorization: Emphasizes deep comprehension of core concepts instead of rote memorization. Learners focus on the "why" and "how" behind knowledge to build meaningful connections.
- Knowledge organization: Concepts are organized into schemas or frameworks that help learners relate the new information to prior knowledge. Encourages categorization and pattern recognition.
- Transfer of learning: Promotes the ability to apply learned concepts to new situations or problems, enhancing adaptability. Focuses on generalization across contexts rather than context-specific skills.
- Active engagement: Learners actively construct knowledge through questioning, discussion, and exploration. Encourages inquiry-based learning methods.
- Concept mapping: visual tools such as concept maps help illustrate relationships between concepts, aiding comprehension, and retention.
- Contextualized learning: concepts are taught within relevant and meaningful contexts to enhance understanding and applicability.

Research indicates that conceptual learning can lead to higher engagement and a stronger capacity for knowledge transfer across different fields (Novak, 2010).

In (green and sustainable) entrepreneurial education, for instance, by grasping principles such as value creation and market demand, students can creatively apply these ideas to identify new opportunities in their business projects.

With a deeper understanding of entrepreneurial frameworks, students can develop greater flexibility, creativity, and strategic foresight, which are intellectual traits necessary to navigate challenges and drive innovation in business contexts.

2.5. Use of Knowledge Graphs for Conceptual Learning

Knowledge graphs (KGs) are structured representations of knowledge that organize concepts and their relationships in a directed graph format, facilitating data integration and retrieval (Paulheim, 2017). They consist of networks of nodes, representing entities (referred to as knowledge points), and edges that denote the relationships between these entities, forming interconnected networks.

KGs typically rely on a formal schema or ontology to define entities and relationships in a real-word context. They can be considered practical implementations of ontologies—formal frameworks or abstract models that define the classes (concepts or categories), the relationships between these concepts, and the specific constraints characterizing a particular domain or area of interest.

While ontologies provide an abstract and foundational description of a domain, KGs encapsulate descriptive or factual information about the real world. They focus on representing actual data and relationships within a domain, making information computationally retrievable and useful for queries and reasoning.

KGs can be formally and computationally expressed using various technologies, including GraphML, a graph exchange language format designed for transferring data between graph visualization tools and other applications (Brandes et al., 2014); the Resource Description Framework Schema (RDFS), a Semantic Web technology for data modeling (W3C, 2014); and the Web Ontology Language (OWL), a Semantic Web modeling and query language (W3C, 2004, 2013).

Among these technologies, special emphasis should be given to the widely used RDF standard for knowledge graph representation (W3C, 2014). In RDF, knowledge is expressed in the form of "triples" (subject–predicate–object), where the subject and object represent entities connected by a predicate that defines their relationship. In this case, each triple conveys a specific fact, illustrating the interrelation between two entities.

KGs are foundational to AI applications, such as semantic search, and recommendation systems. KGs can reinforce knowledge management in AI-driven system, supplying models that are supporting retrieval augmented generation (RAG) to deliver more accurate and reliable solutions in the framework of generative AI systems.

In recent years, KGs emerged as powerful tools in creating digital educational content, as they enable the organization and representation of unstructured information in meaningful, interconnected structures. KGs allow educators to develop content that reflects the natural understanding of subjects by interdependencies between concepts, promoting guiding learning through connected topics. Educational content based on KGs and their abstract representation as ontologies fosters conceptual learning by helping students make connections across various areas in field, and to extract the general principles form particular facts about individual instances of classes of objects.

KGs can illustrate links between principles, enabling students to explore connections and relationships.

KG mapping can enhance critical thinking, as students see how discrete concepts fit into larger frameworks, thus supporting knowledge retention, transfer, and generalization. KGs can provide structures for any educational content, supporting holistic understanding and learning experiences that reflect real-world knowledge interrelation, (Abu-Salih & Alotaibi, 2024; Z. Li et al., 2023).

2.6. Generative AI Chatbots and GraphRAG

In recent years, the development of large language models (LLMs) provoked a revolution in the AI field, transforming human–computer interaction with their remarkable ability to "understand" and generate human-like language (OpenAI, 2024).

Trained on vast datasets, LLMs have been integrated into "generative AI chatbots", impacting activities in many socio-economic sectors, including education (Ghimire et al., 2024).

Despite their outstanding capabilities in language "comprehension" and text generation, LLM-based chatbots have limitations. These include gaps in domain-specific knowledge, outdated information, and proprietary data, all of which fall outside their pre-training data. To address these shortcomings, LLMs can be enhanced through retrieval-augmented generation (RAG) frameworks (Hu & Lu, 2024; Gao et al., 2024).

RAG frameworks improve the quality and relevance of LLM-generated text by incorporating a retrieval mechanism into the generation process, without requiring retraining.

These frameworks query explicitly specified data sources to incorporate factual or conceptual knowledge into the LLM's context, resulting in responses with greater accuracy and specificity. This method gained attention for its performance and adaptability, particularly in generative AI applications requiring field-specific information.

However, traditional RAG systems face challenges in real-world scenarios, such as their inability to capture structured relational knowledge, a limitation referred to as "Neglecting Relationships". GraphRAG addresses these challenges by using pre-constructed graph-based data structures to retrieve relational knowledge (Edge et al., 2024), enabling LLMs to generate more precise and contextually relevant responses. Additionally, graph data, such as knowledge graphs, provide summarized representations of textual information, significantly reducing the input length required for generative AI chatbots.

While LLMs excel at processing pure text, they often struggle with data containing structural relationships, such as graphs. GraphRAG frameworks overcome this limitation by retrieving relevant elements from external graph-structured sources or databases.

These pipelines may also include a preprocessing stage, where structured information is extracted and refined from text corpora or other formats, ensuring efficient and accurate integration of graph-based data.

3. Methods

3.1. Development the of Learning Content for Green Entrepreneurship Education

The content of the e-learning platform for sustainable and innovative entrepreneurial education for engineering students was developed using a four-step methodology:

1. Conducting research to identify various aspects of business practices related to green and sustainable entrepreneurship and exploring opportunities to incorporate these findings into EE experiences through digital learning.
2. Creating digital learning content on green, sustainable, and innovative entrepreneurship and choosing suitable methods to deliver this content to students.
3. Identifying the educational settings to deliver the new courses for green and sustainable entrepreneurship education.
4. Collecting user feedback after a pilot test, and improving the GSB platform's features based on the evaluations from learners and educators.

To date, the first three of the above steps have been successfully completed. Specifically, the first step had five main phases:

1. Literature review: A literature review was conducted to gain insights into technology-enabled entrepreneurship education (EE), the impact of instructional theories for green EE, and the educational context, as outlined in Section 2. Additionally, a review of literature on green and sustainable entrepreneurship, including scholarly articles (Hockerts, 2017; Linnenluecke & Griffiths, 2010; Zhang et al., 2020) and recent online reports (Eurostat, 2023; EC, 2019, 2022) was undertaken.
2. Field research: Field research was conducted through semi-structured interviews with key stakeholders, including entrepreneurs and industry experts. This research aimed to examine and gather information on eco-friendly practices and strategies adopted by businesses in various European countries.
3. Methodology development: a methodology was developed to create learning content from the raw data on green business practices gathered through field research.
4. Creation of digital content: based on the methodology developed in the previous phase, the raw data collected during the field research were converted into a structured digital format using advanced IT technologies, including generative AI.
5. Refining the educational content created in the previous phases according to the feedback received from users in order to ensure that the intended knowledge is effectively acquired upon completing the training.

3.2. Research Methodology for Creating Digital Learning Content

The process of creating digital learning content for green entrepreneurship education combined field research and generative AI with retrieval-augmented generation (RAG) technology and validation by human experts.

The methodology consisted of four main phases:

1. Data collection through field research.
2. Data analysis for creating a repository of case studies on green and sustainable business solutions.

3. Data conversion into digital content for conceptual learning purposes.
4. Data categorization for knowledge graphs creation.

3.2.1. Data Collection Through Field Research

The field research in this study employed a qualitative approach. Data collection was based on semi-structured interviews conducted either face-to-face or through videoconferencing. Sixty-four interviews were conducted with entrepreneurs from seven European countries: Austria, Romania, Italy, Portugal, Greece, Malta, Poland, and Switzerland.

Participants were selected using specific criteria to ensure a diverse and representative sample. All the participants were properly informed about the objectives of the project, and data confidentiality was guaranteed.

This group included companies and entrepreneurs from various industries, such as renewable energy, waste management, and sustainable agriculture. The focus was on micro-enterprises and small- to medium-sized enterprises (SMEs) recognized for their innovative and impactful sustainability practices (see Table 1).

Table 1. Participants at the interviews in SMES by categories and subcategories.

Category	Subcategory	Number of Respondents
Gender	Male	42
	Female	22
	Prefer not to indicate	0
Age	Below 25 years	2
	25–39 years	28
	40–59 years	31
	60 years and above	3
Current position in company	President/owner	35
	Managing director	10
	Department manager	14
	Team manager	5
Size of the company (Staff headcount)	1–9	22
	10–50	26
	50–250	16
Company's business field	R&D	4
	Production	34
	Services	16

The enterprises were chosen based on their engagement in green practices, forming an appropriate sample for the research objectives. The interviews covered questions aimed at gathering examples of green practices across the nine key areas of a business model: key partners, key activities, key resources, value proposition, customer relationships, distribution channels, customer segments, costs, and revenue streams.

Each area was analyzed through the lens of three dimensions—environmental, social, and financial—resulting in a total of twenty-seven categories for mapping examples of green business practices. Additional questions were included in the survey, such as: "What motivated the implementation of eco-friendly business practices in the company?", "What obstacles were encountered during the green business practices implementation?", "What was the positive impact of implementing eco-friendly business practices?", or "To what extent were the measures worthwhile, including financial benefits?"

The translation of the sixty-four interviews into English produced a large volume of textual data, making it evident that computer-aided data processing is necessary.

3.2.2. Data Analysis for Creating a Repository of Case Studies on Green and Sustainable Business Solutions

The data collected from the interviews were organized into a pool of empirical information for each interview. A generative AI system was then used to summarize these data, converting the raw input into concise outputs.

The summarization process resulted in sixty-four summaries, each focusing on a company-specific sustainability practice. These summaries were subsequently reviewed and validated by a team of experts. The experts enhanced the summaries with comments and additional information to ensure accuracy and completeness.

As a result, sixty-four case studies were created and stored in the repository of business solutions for green entrepreneurship, an expandable resource designed for learning purposes. This repository provides learners with real-life examples of business solutions that support sustainability and eco-friendliness.

This approach combined field research, advanced AI technology, and expert validation to produce the digital learning content. The resulting repository can serve as an inspiring tool for learners, offering practical insights into implementing green practices in business settings.

3.2.3. Data Conversion into Digital Content for Conceptual Learning

The data conversion phase was further divided into four stages:

- Information extraction,
- data validation, and
- data organization.

Information extraction: Generative AI and related tools within a retrieval-augmented generation (RAG) framework were used to extract relevant information from the large volume of text collected during field research. RAG is a technique in natural language processing that enhances a generative AI system's ability to produce quality informative responses by retrieving relevant documents or passages from an external corpus and incorporating them as context during text generation.

Using these advanced tools, the textual data collected from the research were divided into smaller, manageable units during a "chunking" phase. These chunks were then stored in a vector database during the "embedding" phase, which was subsequently linked to a generative AI system. Once the vector database was attached to the AI system, the process of extracting sustainability "triggers" began. This was achieved by querying the AI system using prompts. Importantly, the system was configured to generate responses exclusively from the vector database containing information collected from the interviewed companies, rather than relying on its pre-trained parameters.

The queries resulted in the identification of 159 sustainability triggers—specific attributes characterizing environmental and sustainable practices in businesses. These triggers served as the foundational information for developing conceptual learning tools.

Data validation: The validation of the 159 triggers extracted through generative AI and the RAG framework was performed manually by experts involved in the project. Once validated, human experts refined the detailed descriptions of the green practices associated with each trigger to ensure clarity and effectiveness. Using generative AI with the RAG method, trigger names and descriptions were condensed into concise formats, capturing the essence of each green practice.

These condensed names and descriptions underwent additional validation by human experts to ensure accuracy. The approach facilitated visual representations of the triggers and enabled computational representations of the related information, allowing for both quick reference and in-depth exploration via digital tools such as search or query systems.

Data organization: Each trigger in the final list was assigned a short name and two descriptions: one short and one detailed. The triggers were then stored in a non-relational database and assigned unique identification numbers for referencing. This methodological approach ensured that the extracted and validated information was structured, accessible, and ready to support the development of digital tools for conceptual learning in green entrepreneurial education.

3.2.4. Data Categorization for Ontologies and Knowledge Graphs Creation

To further enhance usability, the validated triggers were organized with the help of generative AI and a RAG framework into three primary categories based on the initial focus of the interviews: environmental, social, and economic.

With aid of generative AI through RAG, these three main categories were further divided into sub-categories based on the specific focus of each trigger.

Finally, each trigger was associated with one or more of the nine business model canvas (BMC) building blocks (see Tables 2 and 3, and Figure 1).

The complex, multidirectional relationships between triggers—grouped into categories and subcategories—and BMC blocks, which were further divided into sub-blocks, were computationally represented using knowledge graphs. These graphs were encoded in GraphML, a graph exchange format (Brandes et al., 2014), and the web ontology language (OWL) (W3C, 2004).

Through these computational representations, conceptual classes and their interrelations were formally defined, creating an ontology of the business model's triggers for green and sustainable entrepreneurship.

Table 2. Environmental triggers linked to the customer segments and value proposition blocks of a business model.

Business Model Canvas Block	Environmental Triggers
Customer segments (responsible customers)	148. Eco-friendly customer engagement practices 149. Partner eco-conscious firms 150. Partner eco-conscious NGOs 151. Sustainable institutions
Value proposition	56. Sustainable products and services 57. Reduce environmental impact 58. Local material sourcing 59. Lower transportation costs 60. Use sustainable materials 61. Sustainable food production 62. Minimize packaging waste 63. Closed-loop waste reduction 64. Green products 65. Renewable energy

This effort enabled the further development of an educational ontology and a corresponding knowledge graph. The green business triggers ontology aims to capture key entities and interactions within the context of sustainable business practices for educational purposes. It includes trigger classes and subclasses, BMC blocks and sub-blocks, as well as their properties and relationships. These computational representations were created to support the development of a generative AI system that will serve as a recommendation tool for students, and the development of the digital tools enhancing the conceptual learning.

Table 3. Environmental triggers linked to the BMC's blocks channels and customer relationships.

Business Model Canvas Block	Environmental Triggers
Channels (responsible customers)	107. Online self-service 108. Local material suppliers 109. Sustainable supply chains 110. Waste management logistics 111. Eco-friendly transportation 112. E-commerce websites 113. Digital communication channels 114. Focus on local suppliers 115. Local distribution channels
Customer relationships	83. Sustainable products and services 84. Reduce environmental impact 85. Loal material sourcing 86. Lower transportation costs 87. Use sustainable materials 88. Sustainable food production 89. Minimize packaging waste 90. Zero waste delivery 91. Sustainable logistic processing 92. Eco-friendly delivery

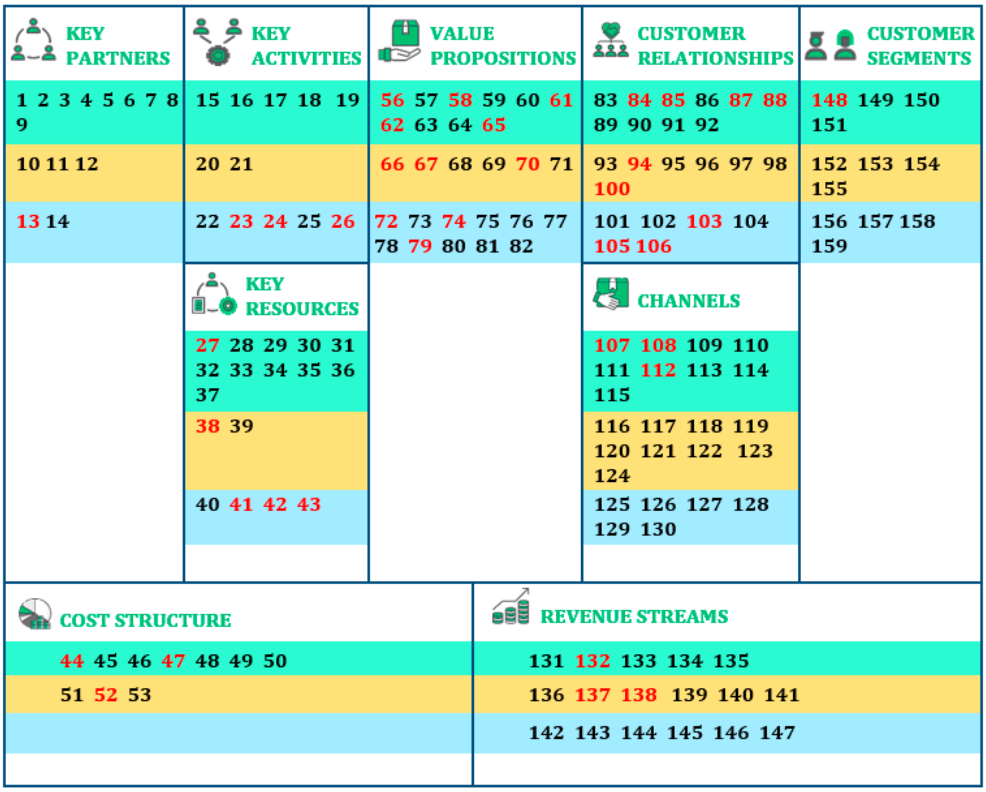

Figure 1. Distribution of the environmental, social, and financial triggers (highlighted with green, light-brown, and light blue), derived from the field research data within the traditional building blocks of a business modeling canvas (BMC). The triggers highlighted in red belong to more than one primary group (environmental, social, and financial).

4. Results

4.1. A Cloud System for Entrepreneurship Education

The cloud system for EE (see Figure 2) includes three digital platforms aimed at fostering skills and practical competencies in business creation and progression:

- The business modeling (BM) e-learning platform, which teaches entrepreneurship through business modeling and financial evaluation of entrepreneurial projects,
- the business innovation and networking (BIN) e-learning platform, which offers interactive lessons on several types of entrepreneurships and supports professional networking in this field, and
- the green and sustainable business (GSB) e-learning platform, which focuses on learning, planning, and modeling of green and sustainable businesses.

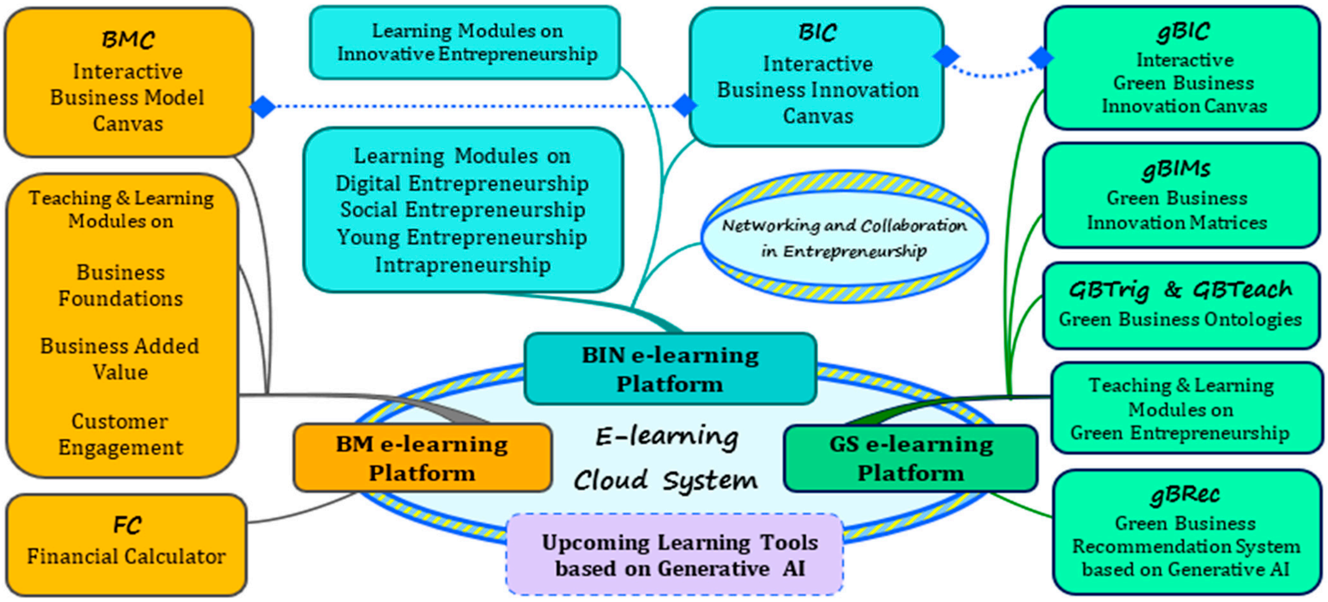

Figure 2. Structure and components of the cloud-based system for entrepreneurship education (CSEE) encompassing three e-learning platforms, each with distinct content and features.

The BM digital environment was the first to be integrated into the EE e-learning system to create the framework of ProBM2 project.

The BM platform provides educational content, focused on the concept of business modeling, as a key element in succeeding with any new business undertaking. It provides digital tools to assist learners in organizing and presenting their business ideas interactively using the business model canvas—BMC, (Osterwalder & Pigneur, 2010). The BMC is a structured framework that describes the key elements of a business. It comprises nine interconnected components (blocks) that outline the main aspects of a business:

- Key partners: identifies collaborating partners, stakeholders, or organizations and outlines their motivations for participating in the business venture.
- Key activities and key resources: specifies the core activities (e.g., production, commerce, and problem solving) and the necessary resources (e.g., physical, intellectual, and financial) to conduct these activities.
- Value proposition and customer segments: represents the value the business aims to deliver (e.g., innovation, cost reduction) and identifies the target beneficiaries.
- Customer relationships and channels: describes the nature of interactions with beneficiaries (e.g., personal assistance, community, and co-creation) and the means (e.g., distribution, communication) through which the value created will be delivered.

- Cost structure and revenue streams: details the major costs involved in the business and the methods of generating income.

The BMC enables users to critically analyze their business ideas, fostering reflection, exploration, and strategic thinking.

The BMC can also serve as a practical organizational tool for developing projects in various fields, including educational initiatives funded by official organization NGOs or private entities. For instance, the educational project, which focuses on creating learning materials and methodologies to teach green and sustainable entrepreneurship, was structured using the interactive BMC tool on the BM platform.

This approach helped establish a general model or conceptual schema for this type of modeling activity (see Figure 3).

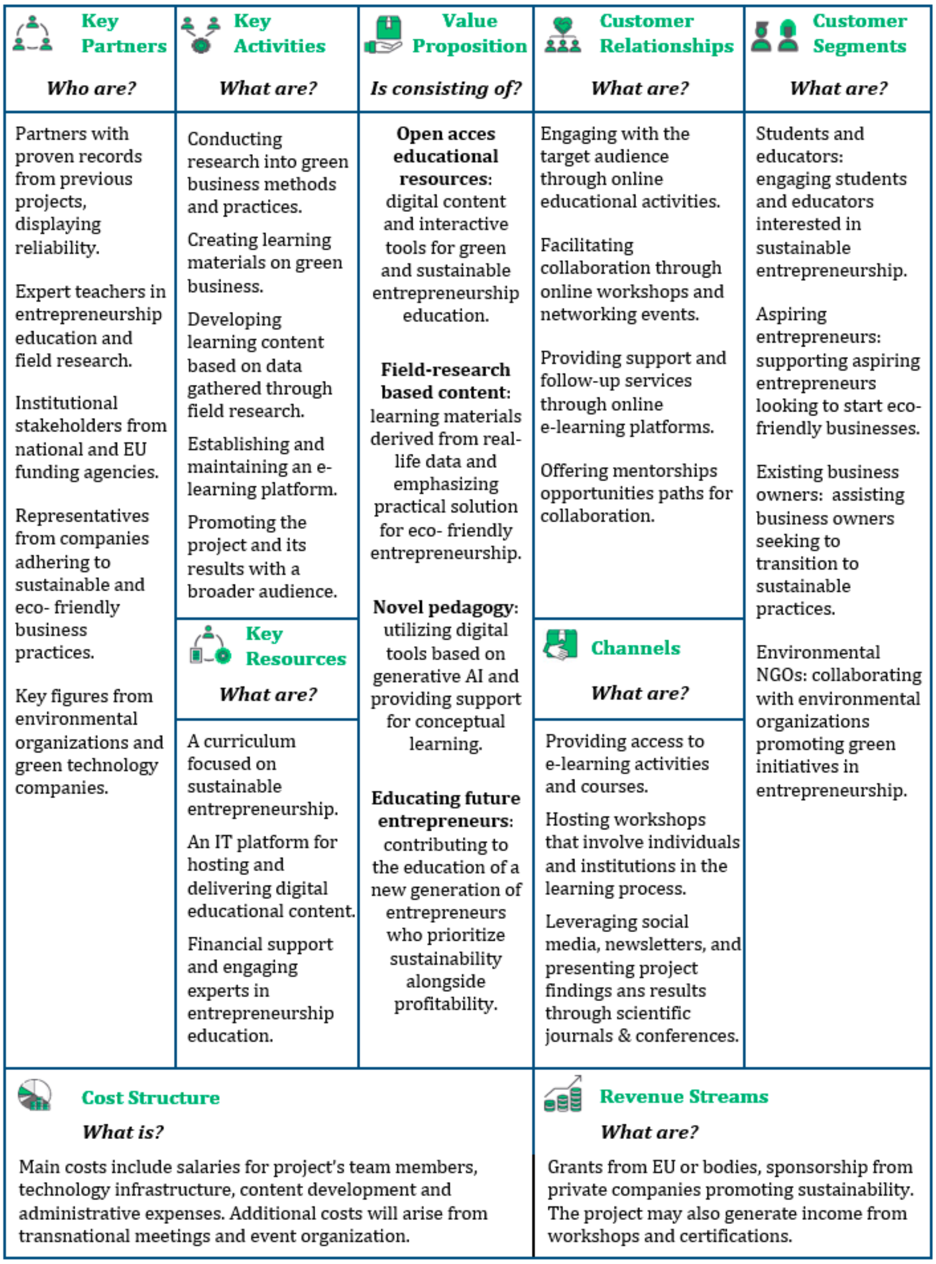

Figure 3. The business model canvas—a graphic synthesis of the conceptual framework for describing a business model.

To improve knowledge delivery through learning experiences, the BM platform organizes the traditional EE content in a format that supports digital micro-learning and mastery learning (Buchem & Hamelmann, 2010; Omer, 2020).

Digital micro-learning breaks educational material into small units, while mastery learning involves brief assessments before and after each unit or lesson. The assessments are incorporated into the learning process, helping learners track their progress.

Together, these approaches reduce time and costs by addressing users' specific learning needs and goals. Micro-learning also gives students greater control of their learning activities, enabling them to choose when and where to engage in training.

The BIN system, the second e-learning platform that has been integrated within the e-learning cloud-system, offers educational content on diverse topics related to the entrepreneurial ventures, such as young, cooperative, and digital entrepreneurship. It offers interactive lessons on business innovation and features a tool to help users incorporate creative changes into their business projects.

Additionally, the BIN platform offers digital tools for professional networking, fostering dialogue and collaboration among educators, students, and business professionals.

The BM and BIN e-learning platforms completed their pilot testing phase, targeting engineering students and adults in continuing education. The pilot testing demonstrated that both platforms are effective and well-received by users.

Many insights were provided for further improvements in terms of new features (use of generative AI and gamification) which can be later incorporated.

GSB—green and sustainable businesses, the third e-learning platform included into the cloud system was meant to support green and sustainable EE through business innovation. It has been developed in the framework of the InnoGreen European project.

The GSB e-learning platform provides educational content and interactive digital tools to help users understand environmental and sustainability aspects, encouraging creativity in their own business projects.

4.2. The Green Business Innovation Canvas

Building on this research, our research team developed the green business innovation canvas (GBIC), a digital framework now integrated into the GSB e-learning platform as an interactive design tool (see Figure 4).

The GBIC enables users to design business projects that prioritize eco-friendliness, focusing on reducing environmental impact, managing resources and energy efficiently, and fostering entrepreneurial creativity.

Once users designed their green business projects, they can assess profitability using the BM platform's online financial calculator.

Integrating the GBIC framework with this tool allows students to turn their entrepreneurial ideas into cost-effective green business models, balancing environmental goals with profitability.

As an inspirational framework, the GBIC provides a view of how to develop business models that incorporate green features and sustainable processes.

It can also provide a straightforward approach for entrepreneurs seeking to include in their business's operations a focus on environmental responsibility.

An additional advantage of GBIC is that it enables the harmonious coexistence of economic and environmental goals. For instance, practices such as resource recycling support the circular economy—a model that aligns with the values of younger generations in business development. As a result, the triggers identified through our research, along with the accompanying digital tools, offer young entrepreneurs a practical guidance for adopting eco-friendly practices in their ventures.

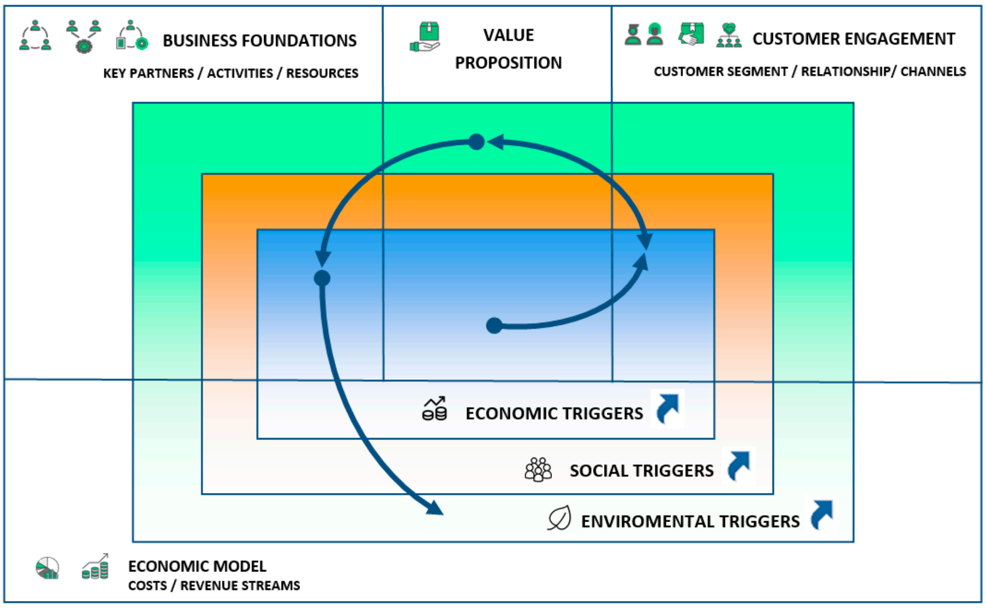

Figure 4. The green business innovation canvas (GBIC) provides a framework to inspire creativity in enhancing the green and sustainable aspects of a business project or enterprise. It defines three primary areas of action by grouping the nine blocks of the business model canvas based on their role within this model. The curved line symbolizes the interdependence among the business aspects within the model's blocks.

4.3. Ontologies for Learning and Teaching Green and Sustainable Entrepreneurship

The examination and in-depth analysis of case studies and trigger content generated through research led to the development of a hierarchical organization of triggers, grouping them into categories (groups) and subcategories (subgroups), as shown in Section 3.2.

The three primary trigger groups were divided into subcategories (subgroups) based on their characteristics, target goals, and potential impacts.

The 70 environmental triggers were classified into eight subgroups, such as Resource Efficiency and Waste Management, Renewable Energy and Emission Reduction, Water and Resource Conservation, Eco-Friendly Products and Services, Innovation and Technology for Sustainability, Sustainable Logistics and Transportation, and the last subgroup, Education, Corporate Social Responsibility, and Community Engagement.

Similarly, the 43 social triggers were classified into five subgroups: Community Engagement and Development, Education and Awareness, Sustainable Operations and Processes, Ethical and Social Responsibility, and Environmental Programs and Standards, and the 46 Financial Triggers were divided into six subgroups (see Table 4).

A review of literature on business models (Freudenreich et al., 2019; Naggar, 2015; Teece, 2018), revealed that each of the nine blocks in the business model canvas (BMC) can be divided into smaller sections or "sub-blocks" based on specific criteria that define the processes or entities within those blocks. These sub-blocks emphasize key aspects of the activities or characteristics associated with each BMC block.

Following this review, the relationships between the features and activities of the BMC sub-blocks and the triggers were analyzed, highlighting the role that triggers can play in sustainable business practices relevant to those sections. Consequently, triggers from the three primary categories were assigned to these sub-blocks based on their characteristics (see Table 5).

Table 4. Subgroups identified within the three primary trigger categories: environmental, social, and financial.

Primary Trigger Groups	Subgroups in Primary Trigger Groups	Triggers in Subgroup
Environmental triggers	Sustainable Partnerships and Collaboration	1, 2, 3, 4, 5, 6, 7, 8, 149, 150, 151, 114, 108
	Resource Efficiency and Waste Management	28, 29, 35, 36, 46, 63, 62, 88, 90,135, 91, 110
	Renewable Energy and Emission Reduction	30, 31, 47, 50, 32, 57, 65, 49, 134
	Eco-Friendly Products and Services	56, 64, 132, 61, 133, 148
	Innovation and Technology for Sustainability	27, 9, 34, 84, 107, 113, 112
	Water and Resource Conservation	37, 48, 44, 58, 45, 59
	Sustainable Logistics and Transportation	83, 92, 91, 111, 115
	Education, Corporate Social Responsibility, and Community Engagement	19, 131, 87, 148
Social triggers	Community Engagement and Development	66, 138, 117, 118, 119, 96, 97, 98, 139, 155
	Education and Awareness	152, 116, 93, 121, 68, 120, 141, 140
	Sustainable Operations and Processes	100, 52, 136, 137, 38, 153, 70, 51
	Ethical and Social Responsibility	124, 154, 69, 21, 71, 122, 123, 12
	Environmental Programs and Standards	67, 94, 20, 95, 99, 10, 53, 39
Financial triggers	Financial Sustainability and Green Finance	13, 14, 23, 24, 26, 42, 43, 55, 146, 147, 159
	Technology and Innovation	54, 72, 74, 75, 79, 82, 101, 105, 106, 142, 143
	Customer and Market Engagement	125, 126, 130, 156, 157, 158
	Operations and Logistics	102, 103, 128, 129, 145
	E-Commerce and Digitalization	76, 81, 104, 127, 144
	Resource Management and Green Practices	22, 25, 40, 41, 73, 77, 78, 80

Table 5. Financial triggers within BMC blocks' sections.

BMC Block	BMC Block-Section	Financial Triggers Within the Block-Sections
Customer segments	Primary customer segment	157. Customer market expansion
	Niche segments	156. Service/products packages
Value proposition	Product/service features	72. Innovative technologies
		79. Eco-friendly practices
		82. Sustainable technology solutions
		102. Eco-friendly delivery vehicles
	Problem solved	77. Assess operations sustainability
		78. Customize/assess sustainability
	Customer gains	146. Green practices funds
		147. Sustainable revenue generation
	Unique selling proposition	158. Transparency

This process supported the development of learning materials and tools for the e-learning platform, modeled in a simplified form on the TRIZ (TRIZ Innovation Center, 2024) contradiction framework, so far referred to as "search for innovation matrices".

This work enabled us to further develop an ontology for learning purposes named green business triggers ontology (GBTrig-O) and a corresponding knowledge graph named GBTrig-KG, green business triggers knowledge graph.

The green business triggers' ontology is trying to capture, for educational purposes, key entities, and interactions in the context of green business practices. It includes the classes and the subclasses of triggers, the blocks and sub-blocks of the BMC, their properties, and relationships.

The green business triggers ontology (GBTrig-O) is designed to integrate general, conceptual knowledge about the elements that shape the development of green business models. Specifically, it formalizes knowledge regarding triggers for green and sustainable practices, the components of the business model canvas (BMC), and their interconnections.

This knowledge is structured into an abstract framework comprising classes of concepts and their inter-relationships, as in the following formal definition:

$$\text{GBTrig-O} = <\text{T, TP, TPS, BMC, BMC-B, BMC-BS, R}>,$$

where

T is the trigger class and TPs are its primary subclasses: environmental, social, and financial triggers.
TPS refers to the subclasses for each of the primary trigger categories.
BMC is the business model canvas class, with the BMC-B subclasses corresponding to the nine blocks of the business model canvas.
BMC-BS refers to subclasses for each of the nine BMC blocks.
R represents the relationship between the classes of concepts and their subclasses.

The GBTrig knowledge graph (GBTrig-KG) is built upon the GBTrig-O ontology and integrates factual knowledge, including triggers, business model canvas components, their descriptions, instances, and relationships.

The formal definition of the GBTrig-KG is as follows:

$$\text{GBTrig-KG} = <\text{GBTrig-O, I, A, P}>,$$

where:

GBTrig-O represents the classes and class-subclass relationships within the ontology.
I refers to instances of concepts or entities within the ontological classes.
A denotes the attributes of entities, including relationships labeled as DescriptionOf, which connect entities/instances to specific values or properties.
P represents the properties of entities, expressed as textual or numerical values.

The visual representation of the GBTrig-KG, referred to as the KG schema (shown in Figure 5), is a directed graph defined as follows:

$$G = (V, E, \{xv\}\ \forall\ v \in V, \{xe\}\ \forall\ e \in E),$$

where

V is the set of nodes representing entities (knowledge points).
$E \subseteq V \times V$ is the set of edges representing relationships.
$\{xv\}\ \forall\ v \in V$ and $\{xe\}\ \forall\ e \in E$ represent the sets of textual attributes (e.g., labels or names) associated with nodes and edges.

The purpose of GBTrig-KG is to provide students with a comprehensive, holistic background for searching, associating, and applying information to foster innovation in developing their green, eco-friendly business projects.

Additionally, a second ontology, named GBTeach-O, was designed for teaching purposes. GBTeach-O incorporates concepts and relationships related to topics, subjects, concepts, and their inner relationships, as well as pedagogies and instructional strategies employed in the newly created course on green and sustainable entrepreneurship.

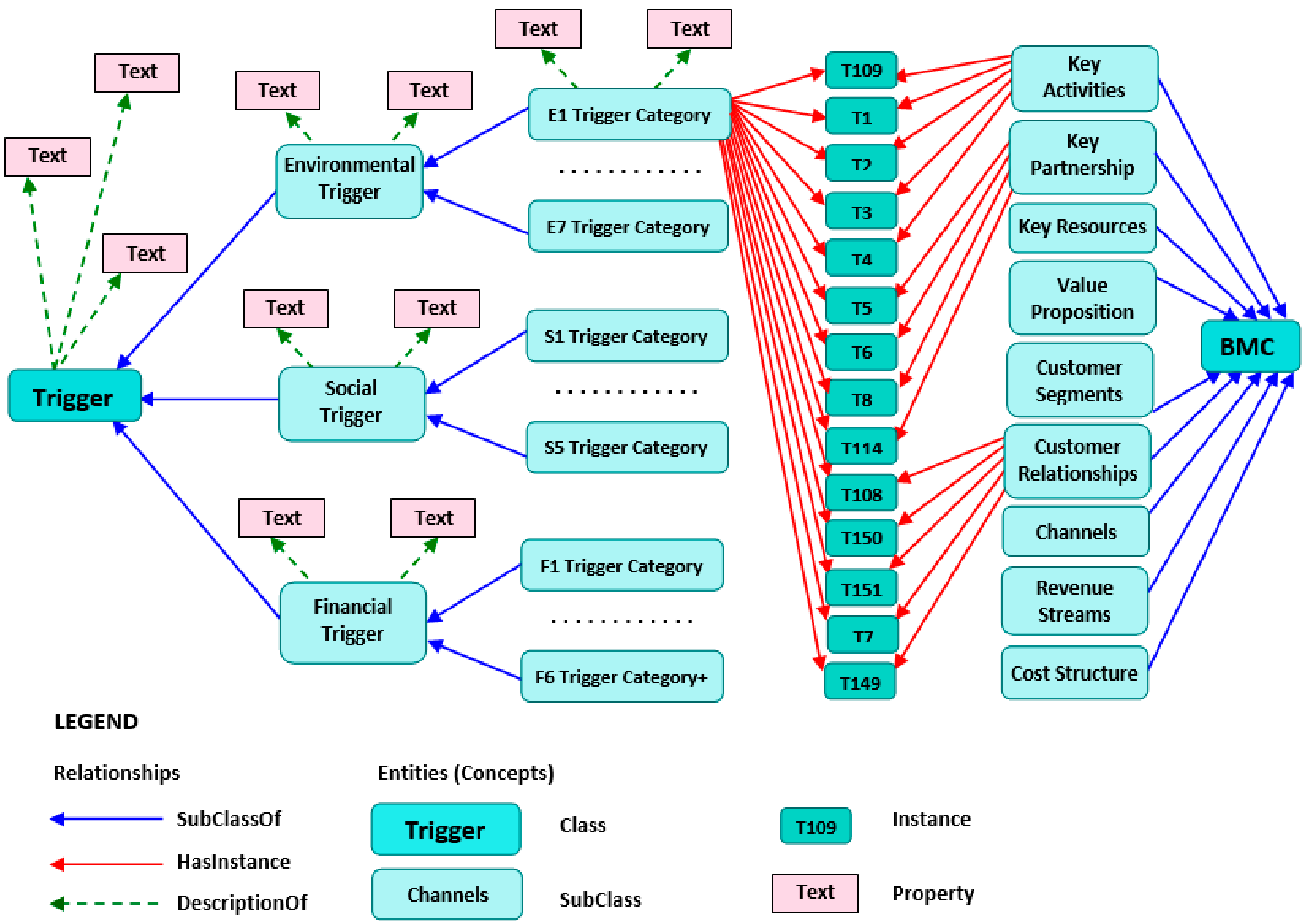

Figure 5. Simplified representation of the GBTrig-KG (green business triggers) knowledge graph design schema. Entities are depicted as classes and subclasses, consistent with RDF/OWL serialization. The "Trigger" class and its three direct subclasses—"Environmental Trigger", "Social Trigger, and Financial Trigger"—are represented.

Both ontologies, GBTrig-O and GBTeach-O, and their corresponding knowledge graphs serve complementary roles: the GBTrig ontology and knowledge graph focuses on the structural and functional aspects of green business modeling, while the GBTeach ontology and knowledge graph supports the pedagogical framework for delivering synthesized, relevant educational content. In this way, these ontologies and their knowledge graphs provide a foundation for integrating green and sustainable entrepreneurship into conceptual learning and teaching contexts.

The newly created ontologies, written in the OWL language, were submitted as input data to Protégé, an open-source ontology editor and visualizer designed for creating semantic knowledge structures, (Debellis, 2021; Stanford Center for Biomedical Informatics Research, 2020). The Protégé information system facilitates knowledge management, allowing users to investigate the relationships between concepts, instances, and their classes within an area of interest. It supports user queries through SPARQL, a query language for retrieving data from knowledge structures, and offers intuitive visualizations of ontological classes, sub-classes, instances, and their connections (see Figure 6).

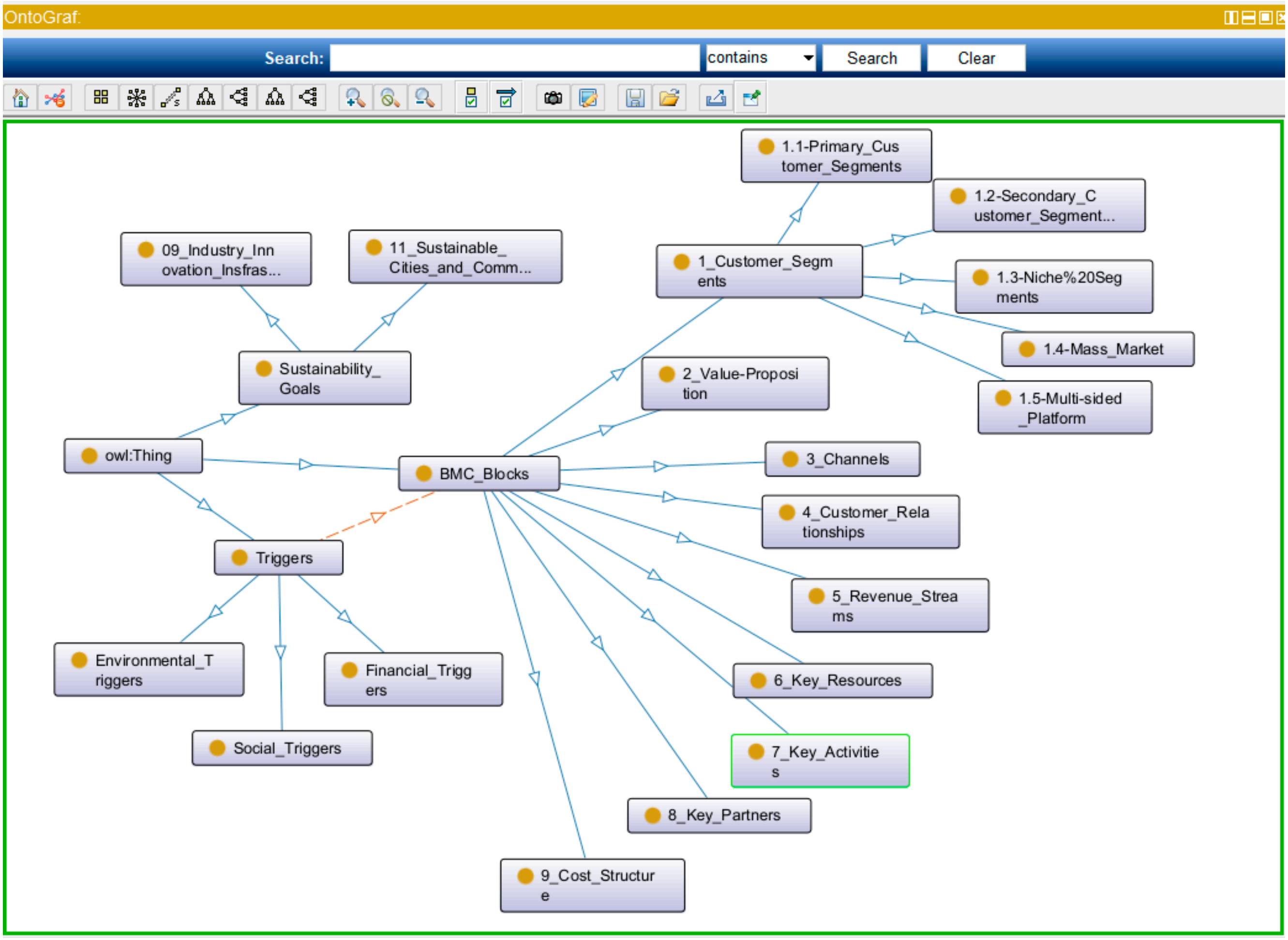

Figure 6. A simplified representation of the green business ontology created using Protégé 2. Three main ontological classes are highlighted: BMC_Blocks, triggers, and sustainability goals.

Additional teaching and learning support tools were created by designing an educational framework that utilizes generative AI, optimized through a graph retrieval-augmented generation (GraphRAG) process, to reference and access the knowledge produced by the research.

This initiative led to the development of a Green Business Recommendation system, a functional stack comprising a generative AI system, custom-built KGs, ready-made or extracted from the "unstructured" learning materials developed in the framework of the project, and a customized prompting guide.

The generative AI system was built using a locally deployed open-source large language model (LLM), functioning as an AI chatbot. The local AI chatbot was implemented to leverage educational materials developed as part of the InnoGreen project, along with the knowledge graphs GBTrig-KG and GBTeach-KG, serialized in RDF/OWL and/or GraphML formats. These materials and knowledge graphs were integrated into the AI chatbot's vector database using retrieval-augmented generation (RAG) and knowledge graph retrieval-augmented generation (GraphRAG) technologies. The InnoGreen project's learning materials, focused on green and sustainable entrepreneurship education, were preprocessed through the RAG pipeline, which consists of several phases:

- An unstructured document chunking phase,
- a concepts and relationships extraction phase,
- the construction of knowledge graphs, and
- the storage of the knowledge graphs into the AI chatbot's vector database.

Once enriched with this specific information, the AI chatbot can respond to user queries, submitted by teachers and students, through tailored prompting.

By utilizing the educational content it was fed, the AI chatbot can deliver precise and relevant answers based on the project's specific educational materials.

The AI chatbot also demonstrated its ability to process and understand detailed information about business activities, identify relevant concepts, and extract green and sustainable practices employed by a business, when applicable.

In this regard, the Green Business Recommendation system can serve as a personal assistant for students, providing accurate answers to their inquiries about incorporating green or sustainable elements into business projects or practices.

4.4. Digital Materials for Learning and Teaching Green and Sustainable Entrepreneurship

The InnoGreen project's approach to supporting green and sustainable entrepreneurship education (EE) was founded on the belief that a diverse collection of educational resources—varying in format, content, and learning objectives—can better inspire and equip users to develop innovative business projects, improve existing business processes, or design new business operations.

This strategy combined traditional educational materials and pedagogies with newly developed content and instructional methods, all created within the InnoGreen project and integrated into the GSB e-learning platform.

As a common feature, all the educational resources were aligned with Bloom's taxonomy (Ruhl, 2024), focusing on levels 3 (application), 4 (analysis), and 5 (synthesis). Additionally, interactivity and visually engaging formats were prioritized to ensure an effective and appealing learning experience. As a result, in its final form, the GSB e-learning platform for green and sustainable business includes:

- Reading materials in various formats and online assessment exercises to build understanding of green and sustainable entrepreneurship concepts and their application in business contexts.
- Practical exercises to foster creativity in business creation and development.
- Gamification elements rewarding the completion of puzzle exercises, designed to enhance retention of key concepts in the field.
- Good practice guides for business modeling, along with case studies and scenarios demonstrating solutions for integrating sustainability and innovation into business projects.
- An interactive green business innovation canvas (GBIC) to help users incorporate sustainability triggers and innovation into their business models.
- Green business innovation matrices (GBIMs) inspired by the theory of inventive problem solving—TRIZ, (TRIZ Innovation Center, 2024), problem-solving schemes, to assist users in identifying green practices for their businesses (Savransky, 2000).
- The Protégé system as a conceptual learning assistant, allowing users to explore and query GBTrig and GBTeach ontologies interactively.
- The Green Business Recommendation system, a generative AI chatbot enhanced with a GraphRAG pipeline, providing answers to questions on implementing sustainability in business projects.

The last three tools—the TRIZ-inspired matrices, Protégé system, and the Green Business Recommendation system—are all knowledge graph-based and were specifically designed to foster conceptual learning, providing users with synthesized insights into green and sustainable business practices.

They aim to enhance problem-solving skills, critical thinking, and innovation capacity, empowering users to address challenges in sustainable entrepreneurship effectively.

4.5. Last Phases in Development of Digital Content Education in Green and Sustainable Entrepreneurship

From the three components of the e-learning system designed and implemented in the context of this research, the BM and BIN e-learning platforms are now fully operational in several European languages. The third component, the GSB e-learning platform, after the integration of traditional and research-based teaching and learning materials, is currently in its final development stage. All the three platforms, BM, BIN, and GSB, provide free access to all the educational resources they encompass and can be used for teaching and learning entrepreneurship in technical fields or for continuing education.

The final stage of the GSB platform development involves pilot testing to gather feedback from educators and learners on the provided educational content and services. This stage consists of three phases:

- Collecting feedback from educators, stakeholders, and entrepreneurs.
- Collecting feedback from students.
- Enhancing the platform's features and services based on user feedback.

The first phase, focused on educators' evaluation, has already been completed. While feedback has been generally positive, both the Protégé system and the GB Recommendation system were seen as innovative but overly technical.

Educators requested a more user-friendly interface to replace the need for direct generative AI prompting and SPARQL queries in Protégé.

The identified shortcomings can be now addressed using the wide range of open-source software and technologies currently available. Already existing integrated solutions, such as RAG pipelines for generative AI content training and tools for building knowledge graphs from unstructured materials, offer the potential to create frameworks with user-friendly interfaces for querying chatbots and receiving recommendations.

The next testing phase will take place in the spring and will involve integrating GSB educational materials into an undergraduate entrepreneurship course for computing engineering students. Feedback will be collected via questionnaires, such as the process used for educators.

Feedback from all users—educators and students—will inform the final phase of platform development, focusing on refining the educational content and tools to optimize the learning experience of users.

5. Discussion

5.1. Analysis of the Results from the Perspective of the Research Questions

To ensure coherence with the research objectives of the project, the results are discussed in relation to the four research questions that framed this study.

RQ1: How can digital systems and tools support traditional and innovative pedagogies in entrepreneurship education?

The digital tools created in the context of this study, such as the green business innovation canvas (GBIC) and AI-driven learning frameworks, enhance both traditional and conceptual learning approaches. These tools integrate interactive, problem-based learning experiences that allow students to explore sustainable business models in a structured, yet flexible, manner. The knowledge graph-based AI recommendation system further personalizes learning, enabling students to retrieve targeted information aligned with their educational needs. These findings confirm that technology-enhanced EE can complement conventional pedagogies by facilitating active engagement and fostering entrepreneurial mindsets.

RQ2: How can digital tools and innovative pedagogical approaches contribute to green and sustainable entrepreneurship education?

The integration of conceptual learning frameworks and AI-driven content generation has proven effective in supporting sustainable entrepreneurship education. By structuring learning content around real-world business triggers, students gain insights into eco-friendly practices through practical, experiential learning. Our study highlights that the GBIC and the TRIZ-inspired matrices effectively bridge the gap between theory and practice, providing learners with actionable tools for designing sustainable business models. These results emphasize that digital pedagogical approaches can foster a deeper understanding of sustainability principles, aligning with the increasing demand for eco-conscious business strategies.

RQ3: How can the digital tools and pedagogical approaches developed in this study foster students' creativity and innovation skills?

Findings from the pilot implementation suggest that interactive modeling tools, such as the GBIC, facilitate creative problem solving by enabling students to visualize and iterate on business models. Additionally, the AI-driven recommendation system, optimized through GraphRAG technology, enhances knowledge retrieval, allowing students to explore multidimensional relationships between sustainability principles, business strategies, and market dynamics. These outcomes support the idea that technology-enhanced learning environments provide a platform for students to develop innovative solutions, encouraging them to design businesses that balance environmental responsibility with economic viability.

RQ4: How can generative AI enhance the creation of effective digital content for technology-driven learning in green entrepreneurship?

The preliminary results are promising in what concerns the transformative potential of generative AI in structuring and delivering educational content. By leveraging knowledge graphs and retrieval-augmented generation (RAG) pipelines, the AI-based system personalizes learning, making complex sustainability concepts more accessible and actionable. The ability of generative AI to synthesize vast amounts of information and provide contextualized, user-specific recommendations reinforces its role as a powerful support mechanism for students and educators alike.

5.2. Contingencies with Other Aspects of the Socio-Economic Development

This research examined the role of digital technologies in entrepreneurial education for a green and sustainable economy. Two key aspects emerged as significant: the development of the digital economy and the impact of the digital divide.

The digital economy encompasses activities driven by digital technologies, such as e-commerce, online communication, services, and data-driven innovation. It relies on the internet, cloud computing, big data, and generative AI to enable efficient interactions, transactions, and decision making across industries. The digital economy enhances connectivity and communication, influencing employment, education, and access to resources and to economic activities. The digital economy also transforms traditional business models, including those centered on green and sustainable practices (OECD, 2024; Ozturk, 2024).

In this direction, a key finding from our study was the use of digital technologies by companies to implement eco-friendly practices in sustainable businesses. Approximately 40% of the sustainable and eco-friendly practices identified through field research, later expressed as triggers, were linked to the digital economy, through the strategies and activities proposed by these companies.

The digital divide refers to the disparity between individuals, communities, or nations with access to digital technologies and those without. This gap impacts access to the internet, digital literacy, and the use of technology for education, healthcare, and economic opportunities. Factors such as income, education, gender, and geography contribute to this divide, exacerbating socio-economic inequalities (Vassilakopoulou & Hustad, 2023; Lythreatis et al., 2022).

In this context, our proposed solutions for technology-enabled entrepreneurship education present a significant challenge: dependence on technological infrastructure. The e-learning platforms suggested for supporting green and sustainable entrepreneurial education heavily rely on internet access and technological infrastructure, which may limit accessibility in regions with insufficient technological resources.

However, this limitation is mitigated by an important benefit: the policy relevance of the study's outcomes. By addressing the digital divide, this research provides a framework for improving access to quality education in underserved regions.

5.3. Comparison of Current Study with Related Research

This section examines how the current article aligns with or diverges from other studies on comparable topics. By comparing methodologies, results, and conclusions, it identifies contrasts in approaches and the contributions of this research to the scientific discourse in the field, emphasizing its relevance in the area of technology-enabled learning for green and sustainable EE. The following topics and articles have been analyzed to achieve the comparison:

- "Green Technology in Education: Key to Sustainable Development" (Sadh, 2019) is an article discussing the role of green technology in education and its importance for sustainable development. It emphasizes the integration of green elements into educational programs to promote sustainability. While research work emphasizes sustainability, the current study focuses specifically on integrating technology-enabled learning into entrepreneurship education, with a detailed methodology for developing digital tools and pedagogical approaches.
- "Technology-Enhanced Learning and Education for Sustainable Development" (Polanco O'Neil, 2019) is an article exploring the intersection of technology-enhanced learning (TEL) and education for sustainable development (ESD). It discusses the challenges and innovations of using technology to support sustainable education. Both papers address the use of technology in sustainable education. However, our article goes further by detailing the development of a cloud-based system and specific e-learning platforms for green entrepreneurship, including the use of knowledge graphs and generative AI.
- "The Impact of E-Learning Technologies on Entrepreneurial and Sustainable Development" (Liu et al., 2023) is an article examining how e-learning technologies can be applied to entrepreneurship education, highlighting the benefits and challenges of integrating these technologies. The current article offers a more comprehensive approach, discussing the integration of e-learning technologies and also presenting a structured methodology for creating digital content and tools specifically for green and sustainable entrepreneurship.

5.4. Limitations

Green entrepreneurship is a dynamic field that constantly evolves with modern technologies and opportunities. Consequently, newly developed educational materials should, through field studies and analyses, reflect technological advancements and the innovative aspects of successful businesses. In this sense, our research within the project InnoGreen focused on collecting and analyzing data from interviews with representatives of enterprises in eight European countries. This research enabled us to create up-to-date educational content, offering learners practical suggestions on how to include green practices in their business projects, and prompting companies to adopt eco-friendly procedures in their ventures.

However, there were some limitations to our research. While this study provides valuable insights into creating novel content and pedagogies for technology-enabled learning in green entrepreneurship, several limitations should be acknowledged:

- Focus on specific technologies: The research concentrated on the use of conceptual learning tools and generative AI. While these technologies demonstrate considerable potential, other emerging tools and pedagogical innovations were not explored. Integrating additional technologies, such as augmented reality, could enhance the scope and applicability of the proposed educational frameworks.
- Short-term evaluation: The effectiveness of the e-learning platforms and tools was assessed primarily through pilot studies and short-term feedback from learners and educators. Longitudinal studies are necessary to evaluate the sustained impact of these tools on learners' knowledge retention and entrepreneurial skills development.
- Sample size and diversity: The empirical research involved a limited number of entrepreneurs and educators from European countries. Although the findings revealed significant aspects of green business practices, the results may not fully represent the perspectives of entrepreneurs from other regions or socio-economic contexts.

Our research should ideally be conducted in a large number of regions or countries at various stages of social or economic development, with a larger sample size. Since the enterprises that participated in the InnoGreen project ranged from micro-enterprises to SMEs, future studies could target a more extended sample.

Using a larger number of respondents and random sampling could yield additional insights. Factors such as economic development levels, national culture, and regional sustainability legislation could also influence the results.

These limitations highlight areas for improvement and provide opportunities for future research. Expanding the geographical reach, incorporating additional technologies, conducting long-term evaluations, and addressing technological barriers are recommended steps to enhance the generalizability and effectiveness of this research.

- Nonetheless, the model developed from this research, utilizing trigger-based case studies, good practice guides, and creativity-supporting learning tools, led to the creation of original educational content and pedagogy.

6. Concluding Remarks

6.1. Study Results and Benefits

A vast amount of quality resources on entrepreneurship, particularly on green and sustainable approaches in businesses, is now available through general knowledge platforms such as the Wiki suite or generative AI systems such as OpenAI ChatGPT, Google Gemini, or Microsoft Copilot.

However, synthesizing core concepts, highlighting their interrelations, and extracting key insights from practical experiences can provide a novel approach to entrepreneurial education focused on eco-friendliness and sustainability. This approach can complement traditional methods by adding a fresh dimension to the information delivery to learners. Additionally, the computational representation of ideas and concepts ensures continuous content updates to reflect advancements in green and sustainable entrepreneurship.

This educational strategy and approach has been implemented in the GSB e-learning platform through a suite of interactive tools, enhancing users' ability to acquire and apply knowledge effectively while stimulating creativity in designing business models. Through support of these tools, students can learn essential aspects from real-world examples and be better prepared to integrate eco-friendly practices into their business projects and future ventures. In this sense, the study results, findings, and benefits are the following:

- Development of a cloud-based system: the article introduces a cloud-based system for entrepreneurship education (CSEE) that includes three e-learning platforms tailored for sustainable entrepreneurship education.
- Developing a methodology for creating digital content: the study presents a step-by-step method to develop digital learning content using data on green businesses gathered from real-world sources, then analyzed and converted them into a structured computational format with the help of advanced IT technologies, such as the generative AI.
- Integration of knowledge graphs: The use of knowledge graphs (KGs) to support conceptual learning is a significant contribution. KGs help organize and represent knowledge in a structured format, facilitating data integration and retrieval. This approach enhances students' understanding of complex concepts and relationships in green entrepreneurship.
- Generative AI and GraphRAG: The article discusses the integration of generative AI chatbots and graph retrieval-sugmented generation (GraphRAG) frameworks. These technologies improve the quality and relevance of AI-generated content by incorporating relational knowledge from pre-constructed graph-based data structures.
- Green business innovation canvas (GBIC): The introduction of the GBIC as a digital framework for designing eco-friendly business projects is another original contribution. This tool helps users balance environmental objectives with profitability, promoting sustainable business practices.
- Ontologies for learning and teaching: The development of the green business triggers ontology (GBTrig-O) and the corresponding knowledge graph (GBTrig-KG) provides a structured framework for integrating green business practices into entrepreneurship education. This ontology supports the creation of educational content that reflects real-world knowledge interrelations.

The study findings and results also demonstrate the feasibility of integrating technology-enabled learning tools, such as generative AI, along with conceptual learning frameworks, into green and sustainable EE. This integration resulted in following benefits:

- Practical implications for educators: the digital tools and pedagogical methods developed in this research provide a scalable model for embedding sustainability into entrepreneurship curricula.
- Practical relevance for users: the concise, easy-to-understand instructional content provided by the conceptual learning tools can accelerate comprehension of principles and processes, fostering goal-oriented and innovation-driven learning.
- Future applications: the study's integration of advanced digital technologies sets a precedent for future innovation in EE, especially in the context of sustainability.

This research bridges critical gaps in entrepreneurship education by combining sustainability principles with cutting-edge technologies, such as generative AI, for both research and educational purposes.

The findings highlight actionable solutions for educators and policymakers to promote eco-friendly entrepreneurship, aligning with global sustainability goals.

6.2. Future Trends and Emerging Issues in Technology-Enabled Learning for Entrepreneurship

The rapid evolution of technology continues to transform education, introducing novel approaches to learning. Understanding these trends is essential for designing inclusive, sustainable, and effective educational frameworks that address global challenges. The future trends can include the following developments:

- Advancements in educational technologies: The integration of AI, virtual reality (VR), and augmented reality (AR) into education is likely to reshape how learners interact with content. These technologies could reduce the digital divide by providing immersive learning experiences, even in resource-constrained settings. However, their implementation requires significant investment and training for educators.
- Increased focus on lifelong learning: As industries continue to evolve, there will be a growing demand for lifelong learning programs to help individuals upskill and reskill. E-learning platforms tailored for sustainable entrepreneurship could play a key role in bridging the skills gap, especially in marginalized communities.
- Decentralized and open education: Blockchain and decentralized platforms might enable more equitable access to learning by allowing learners to document achievements securely and access open educational resources. This trend could mitigate the digital divide by democratizing education.

In contrast to advancements in the field, the emerging challenges in technology-enabled learning for entrepreneurial education may include the following:

- Accessibility and infrastructure challenges: The digital divide remains a critical barrier in many regions where access to technology and reliable internet is limited. Addressing this issue will require collaborative efforts between governments, private sectors, and educational institutions to ensure equitable access.
- Digital literacy gaps: Even with access to technology, a lack of digital literacy can hinder participation in online education. Efforts to build digital skills among learners and educators must accompany the deployment of advanced technologies.
- Economic disparities and equity: While digital tools can reduce some inequities, they may also exacerbate others if technological advancements disproportionately benefit privileged groups. Future strategies should focus on designing inclusive systems that cater to diverse socio-economic backgrounds.
- Data privacy and ethical concerns: The increasing use of AI and data-driven systems in education raises concerns about data privacy and algorithmic biases. Future developments must prioritize ethical frameworks and transparency in technology use.

As technology evolves, its role in education will expand, bringing both opportunities and challenges. Addressing issues such as accessibility, digital ethics, and the digital divide is important to ensure equitable learning environments. By the emerging trends, educators and policymakers can create technology-enabled solutions that foster innovation and inclusivity, building the way for a more connected and empowered future in education.

Particularly, in what concerns the context of entrepreneurship education, future challenges will include ensuring that digital tools foster not only accessibility, but also critical thinking and innovation in sustainability. As technology evolves, educators must balance the need for scalable digital solutions with the demand for human-centric, value-driven learning experiences.

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