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Education 4.0 framework for sustainable entrepreneurship through transdisciplinary and abductive thinking: a case study

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The global challenges and problems that threaten sustainability and human well-being demand the provision of creative, innovative, and affordable solutions so that they are within the reach of different levels of society. From the point of view of Higher Education, this is a major challenge since it is responsible for training new generations with the competencies and knowledge that allow them to respond to contemporary challenges and problems. This study provides a framework to promote sustainable entrepreneurship through transdisciplinary and abductive thinking. This combination of approaches will allow students to identify, analyze, and understand contemporary problems and, through a systematized process based on the "design thinking" design model, propose creative, innovative, and affordable solutions that can be implemented through entrepreneurship mechanisms. The identified findings that will be presented in this work are (i) the relevance of the Education 4.0 model as a reference to promote transdisciplinarity in a current teaching-learning context, (ii) The relevance of "design for sustainable development" as a trigger for sustainable entrepreneurship, (iii) The formation of desirable competencies in the profile of the higher education student based on transdisciplinarity and abductive thinking within the active learning process, and (iv) quantitative and qualitative measurement that allows measuring acceptance and evaluation of the long-term sustainability of the solutions obtained. This work will present the implementation of the proposed framework through a case study. This case study allowed us to identify elements of the proposed reference framework. The case study will address the problem of water scarcity and pollution, describing initiatives to achieve ODS 6, where it explains how sustainable and visionary solutions can be forged through transdisciplinary collaboration and abductive thinking. The project named "STEAM-mural fountain" done by a transdisciplinary working team between academia-society-industry is described, which aims to make technological advances in water treatment and monitoring visible to society.

KEYWORDS

education 4.0, open innovation, sustainable entrepreneurship, transdisciplinary, abductive thinking, educational entrepreneurship, educational innovation, higher education

1 Introduction

In a world where sustainability and human well-being are threatened by significant global challenges, the need to find creative, innovative, and affordable solutions accessible to various social strata has become imperative. Higher education institutions are crucial in this context, as they are tasked with educating new generations with the competencies and knowledge needed to tackle contemporary challenges and problems. From the perspective of Higher Education, this challenge becomes a fundamental task that requires a redefinition of pedagogical and methodological approaches.

In this context, the integration of systems and design thinking into transdisciplinary studies has been explored, emphasizing the importance of an iterative and collaborative process centered on user needs (Pohl et al., 2020). This aligns with the notion of transdisciplinary and abductive thinking, where interdisciplinary collaboration and the search for innovative solutions are fundamental. In this context, the relevance of Education 4.0 as a reference framework for promoting transdisciplinarity in the current teaching-learning context stands out, highlighting the importance of adapting education to the demands of the 21st century (Miranda et al., 2021).

This study embarks on providing a comprehensive framework that promotes sustainable entrepreneurship and leverages the potential of transdisciplinary and abductive thinking (Pohl et al., 2020). By combining these innovative approaches, the study enables educators to identify, analyze, and deeply understand contemporary problems. In that sense, the intersection of sustainability and "design thinking" has been highlighted as a means to address complex issues (Muñoz and Cohen, 2018). In such a way, the structured process based on the principles of "design thinking" allows for the creation of creative, innovative, and profitable solutions that can be implemented through entrepreneurship-related mechanisms. This approach not only prepares educators and subsequently students for future challenges but also actively engages them in the search for solutions that can contribute to a more sustainable world, aligning with the perspective of sustainable entrepreneurship (Rosário et al., 2022). Considering that it is hardly possible to develop student competencies if the educator lacks them. Therefore, prior work with educators is key.

The findings presented in this work cover several key dimensions. Firstly, the study highlights the relevance of the Education 4.0 model, positioning it as a fundamental reference for fostering transdisciplinarity in the current educational landscape (Miranda et al., 2021). Secondly, it underscores the importance of "design for sustainable development" as a catalyst for sustainable entrepreneurship, emphasizing the role of "design thinking" in solving complex problems (Gibbs and Beavis, 2020). Thirdly, the research explores the development of competencies in educators, desirable in the profiles of higher education students, emphasizing the integration of transdisciplinary and abductive thinking in the context of active learning (Rosário et al., 2022).

This article unfolds a detailed analysis of how Higher Education can catalyze sustainable entrepreneurship, utilizing a transdisciplinary and abductive approach. Section 2 presents the vital role of sustainable entrepreneurship within the educational realm, establishing its importance for future development. Section 3 delves into the constructive collaboration between transdisciplinary and abductive thinking, revealing how creative cells can serve as innovation incubators. Section 4 introduces the Education 4.0 approach,

examining its relevance in adapting teaching to contemporary demands. Section 5 describes the "Education 4.0 for Sustainable Entrepreneurship" framework, providing a comprehensive model for sustainability-oriented education. Section 6 covers a practical case study, "Seres de Agua STEAM," showcasing the implementation of the proposed framework. The discussion and conclusions, in Sections 7 and 8 respectively, synthesize the findings and consider their implications for educational practice and future research, concluding with a reflection on the impact and future directions in this dynamic field.

2 The role of sustainable entrepreneurship in higher education

Sustainable entrepreneurship is defined as a business approach aimed at integrating economic, social, and ecological goals within the management and operation of businesses (Rosário et al., 2022). This approach seeks to address critical global issues such as environmental degradation and social inequality by actively considering the environmental and social impacts of business activities. Beyond merely pursuing economic profits, sustainable entrepreneurship endeavors to create economic value ethically and responsibly, thus contributing to a more sustainable future. This approach recognizes the interdependence of economic, social, and ecological aspects in business decision-making, fostering a balance among profitability, social welfare, and environmental conservation.

Hence, this entrepreneurship is posited as a crucial paradigm for sculpting a future that systematically balances economic progress with ecological imperatives and social equity. This business approach is argued to play a vital role in shaping a more resilient and conscious future by incorporating environmental, economic, and social factors into its strategic core (Terán-Yépez et al., 2020; Rosário et al., 2022).

Lastly, Muñoz and Cohen (2018) argue that sustainable entrepreneurship significantly enriches the educational sphere by fostering the adoption of social and environmental responsibility and by stimulating critical thinking development. This outlook emphasizes the necessity of a robust theoretical framework to guide future research and educational practices in this area.

Within higher education, sustainable entrepreneurship emerges as a transversal axis that encourages the integration of theoretical and practical knowledge. Embedding this approach in academic training equips educators to address complex and dynamic issues, enabling the creation of sustainable solutions that can evolve into tangible enterprises.

3 Transdisciplinary and abductive thinking trough creative cells

Transdisciplinary and Abductive Thinking refers to an approach to thinking and problem-solving that involves integrating multiple disciplines and seeking creative and holistic solutions to complex challenges.

Gibbs and Beavis (2020) emphatically argue that integrating diverse disciplines is crucial for addressing global complex challenges, such as climate change and global poverty. This transdisciplinary approach enriches problem understanding by incorporating multiple perspectives and specialized knowledge, also essential for conceiving

and generating new solutions. The synergy from interdisciplinary collaboration facilitates identifying holistic and effective strategies, crucial for tackling the underlying causes of these complex challenges and ensuring a lasting positive impact on society and the environment (Gibbs and Beavis, 2020).

Given the growing complexity of global challenges, integrating transdisciplinary and abductive thinking has become an approach used in Higher Education to construct solutions to complex problems. This strategy is noted for its ability to combine knowledge from various disciplines, promoting a holistic and deep understanding of the complexities characterizing contemporary challenges (Gibbs, 2017). Adopting creative hypotheses through abductive thinking facilitates identifying innovative solutions, transcending conventional responses to address multifaceted issues effectively. This transdisciplinary approach is necessary for academic advancement and the development of critical and creative competencies in teachers and subsequently in students. It's also fundamental for preparing future professionals to contribute to solving global complexities and workplace challenges with sustainable solutions.

In the academic and professional realm, abductive thinking emerges as a key facilitator for transdisciplinarity, a capacity increasingly recognized as essential in solving contemporary complex challenges. Recent literature evidences a significant correlation between abduction and innovative methods in higher education, such as Creative Cells. Gibbs and Beavis (2020) contend that the integration of diverse disciplines is crucial for addressing global challenges. In this context, Creative Cells embody a pedagogical approach that promotes the generation of holistic solutions to multifaceted problems, reinforcing the synergy between interdisciplinary collaboration and abductive thinking.

The studies of Kolko (2010) and Fei (2019) highlight how prototyping and design synthesis, respectively, are processes imbued with abductive thinking, which catalyze the anticipation and creation of innovative solutions in the field of ergonomic design. On the other hand, Okoli (2023) provides a theoretical framework that links abductive reasoning with inductive and deductive theorizing in social sciences, expanding the understanding of abductive thinking as an integral element in transdisciplinary theoretical construction. Consistently, Liem (2019) discusses the importance of prototyping as a dual tool that not only anticipates innovative products and services but also acts as a bridge for the acquisition of new knowledge in ergonomics and design.

Therefore, the authors underscore the relevance of abductive thinking as an imperative for transdisciplinary progress and innovation in Creative Cells. The adoption of this approach in higher education not only encourages critical and creative competence among teachers and students but is also fundamental in preparing future professionals to contribute sustainable and meaningful solutions to global complexities. Therefore, transdisciplinarity, rooted in abductive thinking, stands out as indispensable for fostering an education that transcends technical instruction and nurtures the development of competencies across disciplinary training, thus supporting the emergence of innovative solutions in a world characterized by uncertainty and complexity (Fang et al., 2023).

The relevance of the transdisciplinary approach and abductive thinking in the context of STEM practices highlights the importance of assessing how teachers and students apply knowledge in transdisciplinary contexts (Fang et al., 2023). This finding establishes

a crucial link with the capacity of education in science, technology, engineering, and mathematics (STEM) to promote generating sustainable solutions to complex problems. Highlighting the need for effective assessment tools, the research indicates that enhancing STEAM education quality involves preparing teachers and students to integrate and apply knowledge from multiple disciplines in creating innovative responses to global challenges. This approach aligns STEAM educational practices with sustainable development goals and emphasizes transdisciplinary problem-solving of complex issues.

In this context, the concept of Creative Cells is defined as heterogeneous groups of individuals united by a common purpose to generate innovative solutions to specific challenges (Hess and Torres, 2015). Originally adopted in internal organizational contexts, this approach highlights the value of bringing together people from various disciplines, regardless of hierarchical ranks or areas of specialization. Favoring diversity, creativity, empathy, and motivation promotes a participatory management model. Among its advantages is the fusion of knowledge, experiences, and ideas toward shared goals, resulting in increased productivity and overall satisfaction, and facilitating the emergence of innovative solutions through consensus and comprehensive collaboration.

Adopting the concept of Creative Cells in Higher Education has marked a significant advancement in promoting innovation for solving complex problems through a people-centered approach. This method arises from the need to foster competencies that facilitate the development of transdisciplinary and abductive thinking among members, essential skills for driving creativity, innovation, and adapting to VUCA (volatile, uncertain, complex, and ambiguous) environments, as reflected in the Sustainable Development Goals (SDGs). Creative Cells are distinguished by their non-hierarchical structure and the diversity of their members, which has proven effective in promoting both preexisting and emergent collaboration. By encouraging diversity, mutual respect, and collective creativity, this approach shifts the traditional leader's role to that of a facilitator who promotes equality and active participation. This change reinforces team cohesion and enhances its ability to devise innovative solutions. See Figure 1.

Transdisciplinary thinking is characterized by its focus on "Idea Hybridization," a process that drives the integration of knowledge from multiple disciplines, vital for tackling complex challenges such as water resource management. It is complemented by "Intersectoral Collaboration," which promotes synergy between different faculties and sectors, pushing for unified solutions to shared problems. This approach is further enriched with a "Systemic Approach," advocating for a holistic and connected understanding of problems, and an "Integrated Analysis," proposing a comprehensive evaluation that amalgamates various perspectives and research methods, both crucial for advancing toward sustainability and effective innovation.

In the context of abductive thinking, "Concept Creation" emerges as a key mechanism for developing ideas and solution concepts. This process involves the integration of diverse perspectives and observations, contributing to the generation of original solutions for complex problems. Thus, by combining elements in unconventional ways, it promotes a creative exploration that transcends the limits of established knowledge, thereby facilitating the emergence of hypotheses capable of resolving ambiguous and uncertain situations. "Experimentation and Prototyping" are key stages that allow the materialization of theories into practical solutions, while "Pragmatic

FIGURE 1
Key competencies in transdisciplinary and abductive thinking trough creative cells.
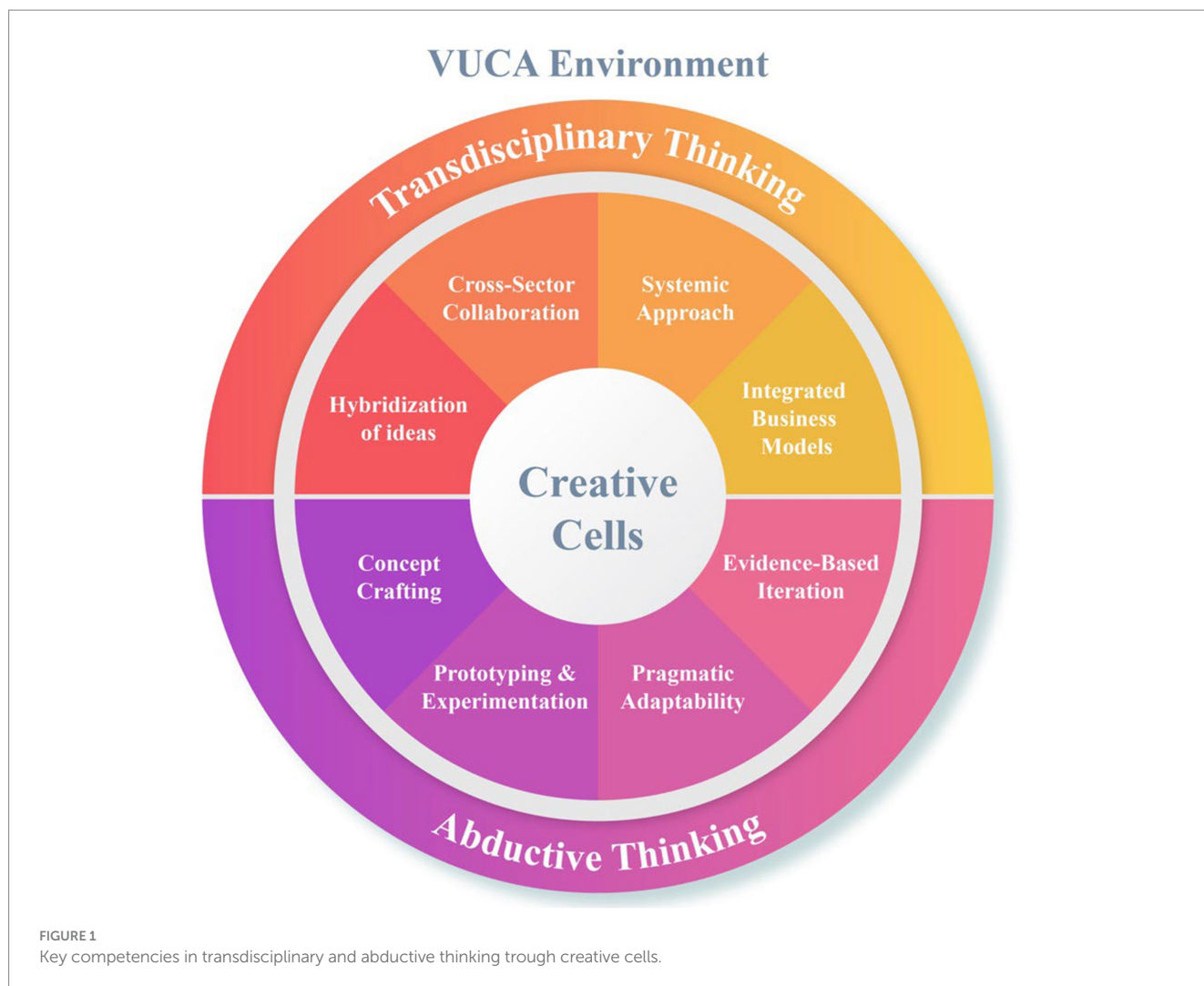
Adaptability" prepares the academic community to adapt to changes and conditions of the real environment. "Design thinking" Evidence-Based Iteration closes the cycle, promoting continuous improvement informed by concrete data, which reinforces the commitment to constant learning and development, essential in modern education and environmental problem-solving.

The incorporation of abductive and transdisciplinary thinking competencies in higher education addresses the need to prepare teachers and students for the complex and changing challenges of the 21st century. Within the context of Education 4.0, this approach is crucial for developing skills that enable innovation and adaptation to VUCA environments. Training in these competencies is achieved through active learning dynamics that immerse teachers and students in real projects, collaborative work, prototyping, and experimentation. By adopting this approach, higher education transcends technical teaching to foster the development of these competencies across their disciplinary training.

4 The Education 4.0 approach

Education 4.0 is established as a theoretical and applied construct that combines advanced technological infrastructure and characteristics of the fourth industrial revolution with innovative pedagogical approaches to forge 21st-century competencies (Konkol and Dymek, 2024). This paradigm is characterized by its focus on active and student-centered learning, where students are the protagonists of their learning process, interacting with content in a critical and creative manner. Thus, it promotes the acquisition of knowledge and skills that are vital for adaptability and solving complex problems, preparing future professionals to be competitive in a labor market that values leadership, creativity, and innovation (Marcial, 2020).

In the literature, Education 4.0 has been recognized as an extension of the "Industry 4.0" concept, which reflects the implementation of technological advancements and characteristic technologies of this era as essential enablers for carrying out teaching-learning processes and active pedagogies (Chakraborty et al., 2023). The Education 4.0 framework moves away from traditional educational theories such as essentialism, instructivism, and behaviorism, and instead adopts contemporary pedagogical philosophies like "cybergogy," "peeragogy," and "heutagogy," which prioritize self-learning practices (Ramírez-Montoya et al., 2024).

According to Miranda et al. (2021), Education 4.0 represents a paradigmatic shift in pedagogical methodologies that align with the needs of 21st-century education, emphasizing the development of soft

and disciplinary competencies that are relevant for the modern professional. Therefore, it is assumed that Education 4.0 seeks to equip students with specialized knowledge in their professional disciplines, complemented with disciplinary, technological, and transversal competencies. Thus, this set of competencies becomes essential for conceptualizing and addressing complex and multifaceted problems that arise in real-world scenarios.

In this context, it becomes essential that from the Higher Education Institutions (HEIs), the Education 4.0 frameworks are promoted, and active teaching-learning processes are carried out. This approach is particularly effective in problem-solving, driving the development of innovative products and services with direct applications in the productive sectors and entrepreneurship projects. Education 4.0, especially when integrated with a training approach in complex thinking, thus emerges as a catalyst for entrepreneurship, stimulating the conception and development of novel products and services. Therefore, through Education 4.0, the classroom is transcended to become a powerful tool in shaping future entrepreneurs and leaders, equipped to address and solve the most pressing challenges of our era. This commitment to education as a catalyst for sustainable change and progress establishes a natural bridge to the next phase of the discourse: the need to educate for sustainability in an interconnected world.

5 Education 4.0 framework for sustainable entrepreneurship

The "Education 4.0 Framework for Sustainable Entrepreneurship" proposed in this study is a pedagogical approach that focuses on human-centered innovation, outlining an educational paradigm that seeks to be a model for the realization of projects aimed at solving concrete problems through a sustainability approach. The methodology to arrive at this framework was based on an integrated analysis of current pedagogical practices and emerging demands in higher education, and on the identification of key competencies required for sustainable entrepreneurship. This review was complemented with analyses of secondary data and focus groups with key educational stakeholders, allowing a deep understanding of the essential competencies to foster sustainable entrepreneurship. Through this process, it was identified that abductive and transdisciplinary thinking are fundamental to navigate the challenges of sustainable entrepreneurship, given their capacity to integrate knowledge from multiple disciplines and promote the generation of innovative solutions from non-evident patterns. These modes of thinking are suitable for training in the context of Education 4.0, as they prepare students to act and adapt in a world characterized by uncertainty and complexity, and to contribute meaningfully to sustainable progress.

Elements such as creative cells are incorporated into this framework as collaborative environments that facilitate the connection between teachers and students from different disciplines, thus allowing the convergence of knowledge and the generation of innovative solutions. The structure of the framework is supported by the interaction with advanced technologies and an informative infrastructure that promote active and student-centered learning, and in turn, empower them for the development and implementation of sustainable entrepreneurship projects.

The "Education 4.0 for Sustainable Entrepreneurship" framework proposed in this work was designed with the intention of providing educators with a methodological scaffolding for the construction of training itineraries adaptable to different educational environments. This scheme aims to identify and assemble the crucial components of a teaching process that is in line with the principles of Education 4.0, thereby facilitating the establishment of active learning methodologies that promote the resolution of real problems. See Figure 2.

The adoption of this framework represents an evolution in higher education pedagogy by offering an approach that not only adapts to a constantly transforming academic context but also provides educators with the tools to design learning experiences that reflect and address the demands of a world defined by uncertainty and complexity.

The methodology adopted for the framework's development is based on the application of a set of predefined metrics, which are directly derived from the framework's pedagogical objectives. The selection of these metrics is grounded on a correlation established between innovative educational practices and successful learning outcomes, evidenced by previous empirical studies in higher education. (i) Projects developed with an emphasis on sustainable entrepreneurship. (ii) Integration of transdisciplinary knowledge. (iii) Capacity for abductive thinking, (iv) Contribution to the SDGs. The choice of these metrics is based on their proven capacity to provide detailed insights into the teaching and learning process and educational outcomes.

This set of metrics allows for an objective and detailed evaluation of the proposed framework's progress and effectiveness. The practical application of these metrics and the accumulation of resulting data have proven to be adequate methods for measuring the quality of the training process and its alignment with global sustainability standards. Adopting this methodological approach ensures that educators and students trained under this framework will possess the necessary skills to successfully face the challenges of sustainable development.

The "Education 4.0 for Sustainable Entrepreneurship" framework is articulated through an implementation model divided into three essential phases, each designed to address specific aspects of the educational process and sustainable entrepreneurship. These phases are established to create a coherent and effective flow from conceptualization to project evaluation, ensuring that learning is both relevant and applicable to contemporary challenges.

Phase 1. Formation of creative cells and definition of challenges. Transdisciplinary groups called "creative cells" are established. These groups, formed by diverse individuals directly or indirectly linked to the challenge at hand, dedicate their efforts to a thorough analysis to determine overlaps between their varied areas of knowledge. This analytical process is essential for identifying and agreeing on a frequent problem that will be their collaborative project's focus. The identification of this shared problem, derived from the intersection of various disciplines, is crucial for directing innovation and entrepreneurship toward sustainable and human-centered solutions.

Phase 2: Transdisciplinary process and abductive design. During the second phase, the creative cells go through stages of design and development based on the principles of transdisciplinary and abductive thinking. Here, the creation of concepts and the integration of knowledge are encouraged, where collaboration and shared vision among disciplines result in the design of educational experiences that stimulate critical thinking and creativity. This approach promotes an adaptive pedagogy that not only aligns with

FIGURE 2
Education 4.0 Framework for sustainable entrepreneurship.
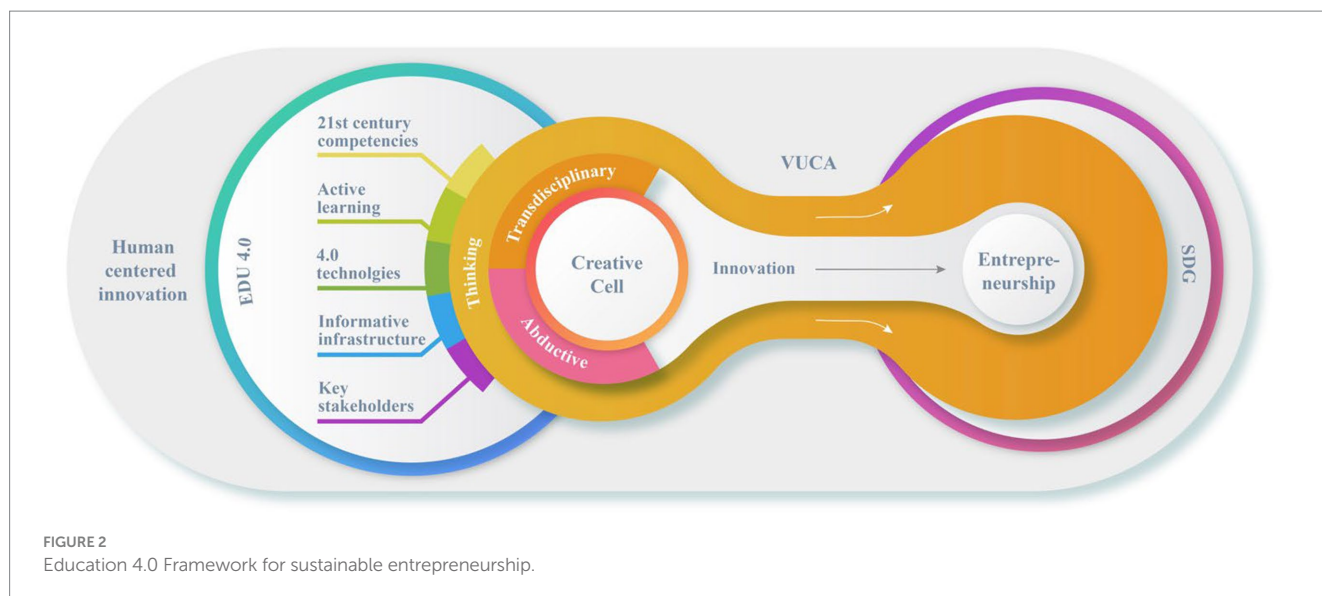
the current needs of students but also prepares future professionals to contribute effectively and meaningfully in a complex and constantly changing world.

Phase 3. Continuous evaluation and adjustments based on results. The final phase focuses on evaluating the process and the outcomes achieved. Specific metrics are applied to measure the effectiveness of sustainable entrepreneurship projects and the quality of knowledge integration. The collection and analysis of data allows for the assessment of the initiatives' contribution to the SDGs and provides essential feedback for adjusting in the educational framework. This cycle of evaluation and improvement is fundamental to ensure the relevance and sustainability of learning.

6 Case study: Seres de Agua STEAM

The "Education 4.0 for Sustainable Entrepreneurship" framework is established as a fundamental pillar for educational transformation toward sustainability in higher education. Within this context, the case study "Seres de Agua STEAM" exemplifies the practical application of this framework, highlighting its effectiveness in fostering key competencies and innovative management of natural resources.

Developed in a university setting, the "Seres de Agua STEAM" project focuses on the critical issues of water scarcity and pollution. Through the integration of STEM methodologies and Design Thinking, the project embodies the values of interdisciplinary education and project-based learning, preparing educators to be pioneers in sustainable water management and educational innovation.

In the following sections, it will detail how the "Seres de Agua STEAM" project aligns with each of the three phases of the "Education 4.0 for Sustainable Entrepreneurship" framework, demonstrating how transdisciplinary collaboration and abductive thinking can materialize in educational initiatives that address challenges and promote sustainable development.

Phase 1: Formation of creative cells and definition of challenges. In the first phase of the "Seres de Agua STEAM"

project, creative cells were formed by bringing together teachers, researchers, entrepreneurs, and professionals from various STEAM disciplines. This multidisciplinary team dedicated itself to the identification and deep analysis of problems related to water management, using "design thinking" methods to empathize with users and understand the dimensions of the challenge. Through this analysis, the central objective of the project was defined: to develop an educational approach that used art and science to raise awareness about the importance of water and its sustainability (Figure 3).

Phase 2: Transdisciplinary process and abductive design. During the second phase, the creative cells applied transdisciplinary and abductive thinking to devise solutions. Ideas were generated, and innovation was fostered through the integration of specialized knowledge in areas such as biology, environmental chemistry, engineering, and art. This ideation process led to the design of the "STEAM-mural fountain," an installation that functioned as an educational tool and art piece, providing a visual and functional representation of water cycles and the issues associated with their conservation. See Figure 4.

Phase 3: Evaluation and adjustments based on results. In the third phase, the "STEAM-mural fountain" underwent a series of evaluations to measure its educational impact and effectiveness in promoting sustainable practices. Data were collected through feedback surveys, observations of student interactions, and public engagement with the installation. The information gathered was used to make iterative adjustments to the design and pedagogical approach of the project, ensuring that the learning and sustainability objectives were met and aligned with the SDGs. See Figure 5.

Technical challenges emerged during both the construction and utilization of the wall. Developing suppliers capable of building the wall within 4 months was a primary obstacle, given their lack of experience with such innovative projects. Additionally, the wall needed to integrate with cutting-edge technologies like levitating drops and healing fabrics. Water analysis on campus was conducted using water droplet levitation and spectrometry, while fabrics made of functionalized carbon nanofibers were designed to tackle water hardness issues. Although a commercial filter was initially adapted for
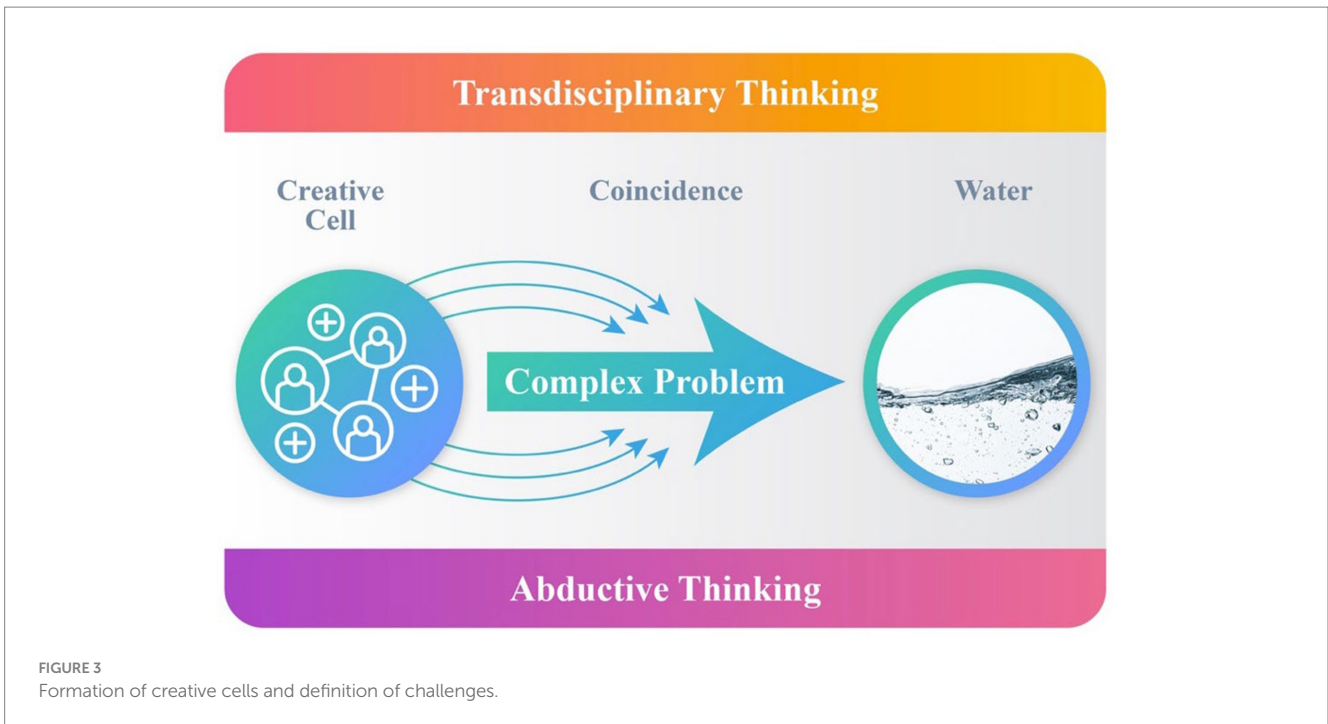
FIGURE 3
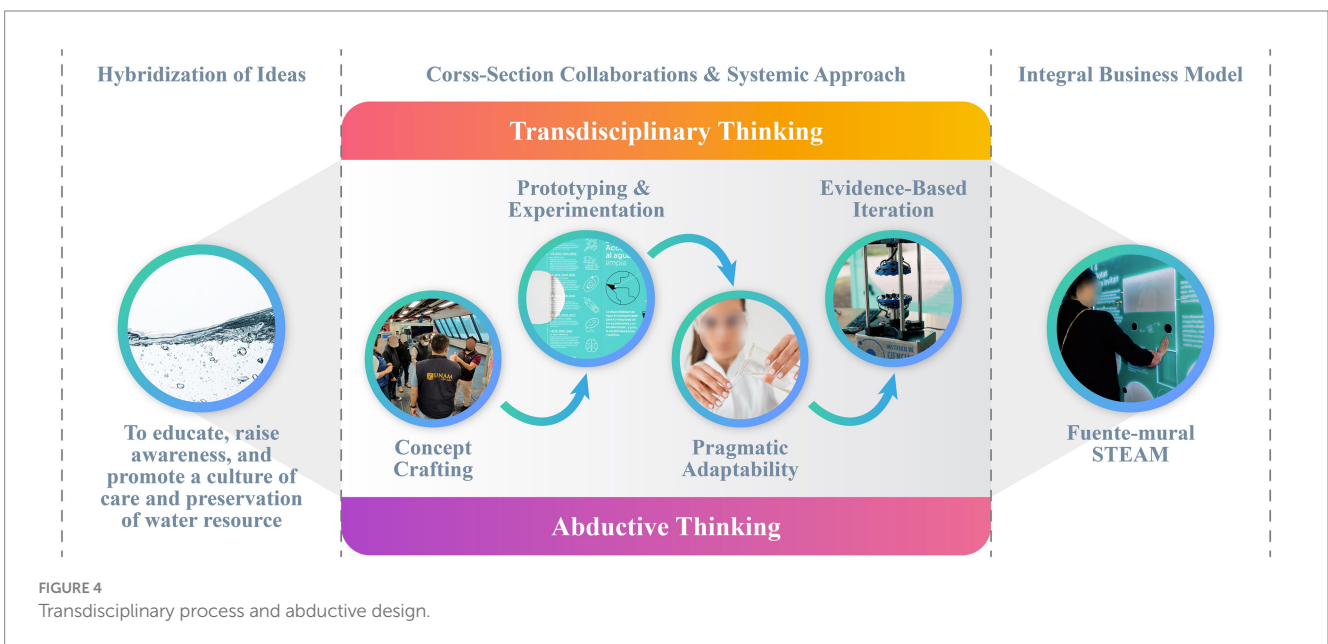Formation of creative cells and definition of challenges.

FIGURE 4
Transdisciplinary process and abductive design.

use at the water fountain during the inauguration, it was later removed due to the fabric's inability to withstand the water flow force.

In conclusion, "Seres de Agua STEAM" represents an exemplary case study that effectively incorporates aspects related to Sustainable Entrepreneurship, Transdisciplinary and Abductive Thinking, and the Education 4.0 Framework, directly contributing to the achievement of Sustainable Development Goal 6 (SDG 6) of clean water and sanitation. Through this STEAM immersion experience, educators and students not only acquire knowledge but also develop entrepreneurial skills, tackle complex problems in a transdisciplinary manner, and experience technologically advanced education. This project serves as an inspiring model for 21st-century education.

7 Discussion

The adoption of transdisciplinary approaches significantly enhances the ability to solve complex problems. This finding, resonating with global trends in education, points to the effectiveness of blending disciplines and approaches in generating innovative solutions. Theorists like Pohl et al. have emphasized the importance of transdisciplinary collaboration in education, while other studies highlight challenges in the effective integration of diverse knowledge. Transdisciplinarity, as an educational practice, poses challenges but is crucial for preparing educators and students for the future labor market and interdisciplinary research, starting with the importance of

Phases. 1 Conceptualization and Content Development and Learning Sequence

Phases. 2 Interaction and touchpoint design

Phases. 3 Final prototypes built at Monterey Campus, and Digitization of the wall through a website
https://seresdeaguasteam.com/

developing competencies first in educators so that they can subsequently develop them in students.

The ability to employ abductive reasoning is fundamental in the educational process, leading to innovation and adaptability in changing contexts. Despite the lack of a direct measure in this study,

the literature suggests that its promotion in higher education can enhance the preparedness of educators and students for emerging challenges. Theorists like Robinson and Aronica (2016) support this view, although Hirsch (1988) points to the need for more structured teaching methods. Promoting abductive thinking in higher education

has implications for both curriculum design and research into pedagogical methods.

The "Education 4.0 for Sustainable Entrepreneurship" framework has proven to be an effective tool for fostering entrepreneurial skills and leadership among educators and students. Although this study is not based on quantitative data, the existing literature validates the relationship between innovative educational approaches and the development of entrepreneurial competencies. Researchers like Drucker (2020) have observed similar outcomes, while Kolb (2014) highlights the importance of practical learning contexts. The implementation of educational frameworks that emphasize entrepreneurship and innovation is crucial for students' professional development and represents a fertile field for future research.

The contribution to the Sustainable Development Goals through educational projects has been reaffirmed as a valuable practice in higher education. Without direct reference to data from this study, the consensus in the specialized literature suggests that initiatives like "Seres de Agua STEAM" can have a positive impact on achieving these global goals. Aligned with the perspective of Koundouri et al. (2024), but contrasting with Easterly's (2021) critique on practical application, the integration of the SDGs in education reflects a commitment to sustainability that is essential both for current educational practice and for guiding future research.

8 Conclusion

This study has explored and validated the "Education 4.0 Framework for Sustainable Entrepreneurship" as a key pedagogical tool for addressing global sustainability challenges. It has been demonstrated that the framework is effective for developing the competencies and knowledge required in new generations to address and solve contemporary problems through a systematic process based on the "design thinking" model.

i   The relevance of the Education 4.0 model has been established, highlighting its utility as a reference for promoting transdisciplinarity in current teaching and learning contexts, thus facilitating the integration of knowledge and skills crucial for sustainable entrepreneurship.

ii "Design thinking for sustainable development" has been identified as a catalyst for sustainable entrepreneurship, encouraging students to think critically and creatively to propose viable and accessible solutions that align with society's needs.

iii The development of competencies in educator's desirable in higher education students has been enriched through the adoption of transdisciplinary and abductive thinking, which are fundamental for innovation and adaptation to complex and changing environments.

iv The implemented quantitative and qualitative measurement methodology provides a tool for assessing the acceptance and long-term sustainability of the proposed solutions, underscoring the importance of continuous evaluation and feedback in the educational process.

The case study of the "STEAM-mural fountain" illustrates how transdisciplinary collaboration and abductive thinking can materialize into initiatives that not only educate and raise awareness about water scarcity and pollution but also promote sustainable and visionary solutions. This project highlights the synergy between academia, society, and industry, and demonstrates how higher education can be a vehicle to showcase technological advances and foster sustainable progress aligned with the Sustainable Development Goals, particularly SDG 6.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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