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Data science engineering: curricular management for responsible production and consumption

Ingeniería de ciencias de datos: gestión curricular para la producción y el consumo responsables

Engenharia de ciências de dados: gestão curricular para a produção e o consumo responsáveis

Abstract

Introduction: given the rapid pace of technological change, Data Science engineers will play a crucial role in driving sustainable innovation. By applying data analysis, machine learning, and artificial intelligence, they can optimize resource use, improve energy efficiency, and develop predictive models to help mitigate social and environmental risks. **Objective:** to integrate sustainability into business education, specifically in the context of the course "Fundamentals of Business Organization" in the Data Science degree at the Universitat Politècnica de València (UPV, Spain). **Method:** this qualitative and constructivist research is based on an educational action-research project in the FOE course. It analyzes transversal competencies and applies the Pattern Categorization Framework through practical activities, integrating sustainability into business analysis. A final activity is proposed that incorporates this tool into the course. **Results:** a methodology is designed to introduce "Social and Environmental Commitment" into the training of Data Science engineers. **Conclusion:** students will be able to address social, environmental, and economic challenges with ethics and professional responsibility, guided by the Sustainable Development Goals, particularly the goal of Responsible Production and Consumption.

Keywords: responsible production and consumption, data science engineering, pattern categorization framework

Resumen

Introducción: dada la rapidez de los cambios tecnológicos, los ingenieros en Ciencia de Datos desempeñarán un papel crucial en el impulso de la innovación sostenible. Al aplicar el análisis de datos, el aprendizaje automático y la inteligencia artificial, pueden optimizar el uso de recursos, mejorar la eficiencia energética y desarrollar modelos predictivos que ayuden a mitigar riesgos sociales y medioambientales.

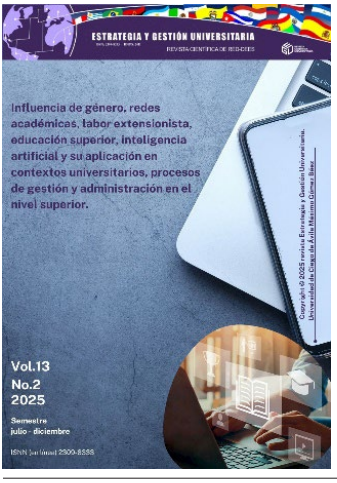
Objetivo: integrar la sostenibilidad en la formación empresarial, concretamente en el contexto de la asignatura "Fundamentos de Organización Empresarial" del Grado en Ciencia de Datos de la Universitat Politècnica de València (UPV, España). **Método:** esta investigación cualitativa y constructivista se basa en una investigación-acción educativa en la asignatura FOE. Se analizan competencias transversales y se aplica el Marco de Categorización de Patrones mediante actividades prácticas, integrando la sostenibilidad en el análisis empresarial. Se propone una actividad final que incorpora esta herramienta en la asignatura. **Resultados:** se diseña una metodología que introduce el "Compromiso Social y Ambiental" en la formación de ingenieros en Ciencia de Datos. **Conclusión:** los estudiantes pueden abordar los retos sociales, ambientales y económicos con ética y responsabilidad profesional, guiados por los Objetivos de Desarrollo Sostenible, en particular, el de Producción y Consumo Responsables.

Palabras clave: producción y consumo responsables, ingeniería ciencias de datos, marco de categorización de patrones

Resumo

Introdução: dada a rapidez das mudanças tecnológicas, os engenheiros em Ciência de Dados desempenharão um papel crucial no impulso à inovação sustentável. Ao aplicar análise de dados, aprendizado de máquina e inteligência artificial, eles podem otimizar o uso de recursos, melhorar a eficiência energética e desenvolver modelos preditivos que ajudem a mitigar riscos sociais e ambientais. **Objetivo:** integrar a sustentabilidade na formação empresarial, especificamente no contexto da disciplina "Fundamentos de Organização Empresarial" do curso de Ciência de Dados da Universitat Politècnica de València (UPV, Espanha). **Método:** esta pesquisa qualitativa e construtivista baseia-se em uma investigação-ação educacional na disciplina FOE. São analisadas competências transversais e aplicado o Marco de Categorização de Padrões por meio de atividades práticas, integrando a sustentabilidade na análise empresarial. Propõe-se uma atividade final que incorpora essa ferramenta à disciplina. **Resultados:** é elaborada uma metodologia que introduz o "Compromisso Social e Ambiental" na formação de engenheiros em Ciência de Dados. **Conclusão:** os estudantes poderão enfrentar desafios sociais, ambientais e econômicos com ética e responsabilidade profissional, orientados pelos Objetivos de Desenvolvimento Sustentável, em especial o de Produção e Consumo Responsáveis.

Palavras-chave: produção e consumo responsáveis, engenharia de ciência de dados, estrutura de categorização de padrões



Introduction

In the current context, universities are called upon to play a crucial role in training professionals capable of addressing global challenges such as climate change and social inequality (Bracho Fuenmayor, 2022; Raimo et al., 2024; Díaz-Romero et al., 2025). The Universitat Politècnica de València (UPV, Spain) has taken on this challenge by integrating the Sustainable Development Goals (SDGs) into its strategic plan, promoting an education that not only technically prepares students but also instills a social and environmental commitment (Boni et al., 2019). In this regard, engineering education is transitioning toward a competency-based approach that better responds to current needs (Malhotra et al., 2023). Furthermore, the incorporation of critical topics such as safety in Industry 4.0 necessitates updating the curriculum to address these challenges (Qian et al., 2023). Thus, the course "Fundamentals of Business Organization" (FBO) in the Data Science Degree has become a key space for integrating sustainability into the training of future engineers, where human-AI collaboration can contribute to competency-based curriculum development (Padovano & Cardamone, 2024).

The Data Science Degree at UPV, launched in the 2021/2022 academic year, prepares students to lead data analysis projects across various fields, including industrial process improvement, risk analysis, product design, and decision-making within organizations.

Currently, data forms the foundation of our understanding of the world; from vehicle movements to temperature monitoring in hospitals, every process requires data for its operation (Ahadov et al., 2019; Bonfield et al., 2020; Bellucci et al., 2022). The objective of the Data Science Degree is to train professionals capable of generating knowledge from data. By learning to design data collection processes in diverse areas, including industry, graduates will be equipped to lead data analysis projects aimed at optimizing industrial processes. Moreover, acquiring skills to process, analyze, and integrate data from multiple sources will enable engineers to extract valuable information and effectively communicate strategies for informed decision-making.

During the first semester of the first year of the Data Science degree at UPV, students take the course "Fundamentals of Business Organization" (FBO), offered by the Department of Business Organization (DBO) at UPV. This course is positioned at the beginning of the degree and provides students with a foundation for their entry into the job market. Understanding the basic principles of business management is useful for guiding their future careers, as well as delving into the relationship between business management and data science, particularly focusing on aspects related to the management of business information systems and data processing for improvement in direction, management, and business communication.

The FBO course introduces fundamental concepts related to business organization and economics, addressing the functions of Organizational Management. It covers key topics such as business theory, organizational structure, socioeconomic environment analysis, strategic management, human capital management, as well as market models and competitiveness. Additionally, it examines various functional areas, including financing and investment systems, production and operations management, and marketing and commercialization

systems.

However, technical competence or business knowledge alone is insufficient for a successful transition to the rapidly evolving and volatile job market (Ahmad et al., 2022; Bizami et al., 2023; Bahroun et al., 2023). Companies increasingly emphasize that graduates often struggle to apply the knowledge acquired in real-world scenarios, arguing that higher education institutions (HEIs) remain focused on theoretical teaching rather than applied learning and the development of functional skills (Direito & Freitas, 2024; García-Hurtado et al., 2024). Beyond technical experience, transversal skills such as adaptability, teamwork, and effective communication are fundamental to complement data science competencies and pave the way for long-term professional success (Škare et al., 2022; Villazon Montalvan et al., 2024). Indeed, a recent survey conducted at UPV (UPV, 2024) reinforces this perspective, revealing that even recent graduates acknowledge the importance of transversal skills and often feel unprepared in these areas.

On the other hand, the current climate emergency and other sustainability crises threaten the well-being and development opportunities of future generations. Collective human activities have altered Earth's ecosystems to the point where our very survival is at risk (Curren, 2009). Therefore, it is essential to learn how to do things differently; to develop the knowledge, skills, values, and attitudes necessary for making informed decisions and taking both individual and collective actions in response to local, national, and global urgencies.

It is at the intersection of technical, business, and transversal competencies that the skill of “Social and Environmental Commitment” is proposed for incorporation. This implies acting with ethics and professional responsibility in the face of social, environmental, and economic challenges, guided by democratic principles, fundamental values, and the Sustainable Development Goals (SDGs). To foster this skill, a learning process centered on the active participation of students, in collaboration with their professors and peers, is proposed (Alarifi et al., 2016; Henri et al., 2017; Gómez-Ríos et al., 2023). Through this approach, students are encouraged to take an active role as agents of social change by utilizing the Pattern Categorization Framework. This framework, developed by the authors (Esteban-Amaro et al., 2024), is considered a key tool for facilitating the transformation of engineering research ideas into real-world applications, with a focus on sustainability and the circular economy.

In this study, the cross-disciplinary competencies currently developed in the FBO course will be initially analyzed. Subsequently, the Pattern Categorization Framework will be explored as a tool to promote sustainability and the circular economy. The objective is to integrate sustainability into business education, specifically within the context of the “Fundamentals of Business Organization” course of the Data Science degree at the Universitat Politècnica de València (UPV, Spain).

Methods and materials

The research adopted an educational action-research methodology (López Velázquez et al., 2020; Latorre, 2005) with a qualitative and constructivist approach (Fierro et al., 2000), applied in the FBO course of the Data Science degree at UPV. This methodology enhances educational processes through cycles of planning, action, observation, and reflection. Through group activities such as PESTEL, SWOT, and Value Chain analysis, competencies such as innovation, teamwork, communication, and social and environmental commitment are developed.

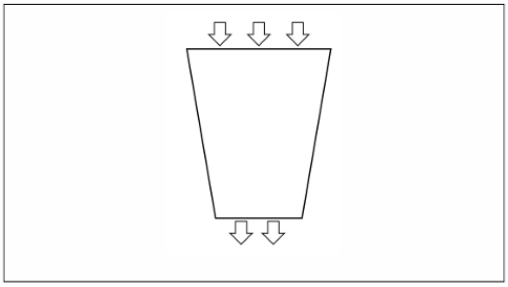
An activity based on the Pattern Categorization Framework (Esteban-Amaro et al., 2024) was included to address Sustainable Development Goal 12 and integrate business sustainability, promoting reflective and experiential learning. The program develops five cross-disciplinary competencies, with FBO particularly promoting innovation, teamwork, and communication. These competencies were addressed through creative problem-solving, collaboration, and presentations tailored to the audience.

During the semester, students analyzed a real company using tools such as PESTEL (Kotler, 1967), Porter's Five Forces (Porter, 1989; Bell & Rochford, 2016), Value Chain (Porter et al., 1985), SWOT (Learned et al., 1969; Bell & Rochford, 2016; Puyt et al., 2023), BCG Matrix (Hambrick et al., 1982), and Porter's Strategies, while also evaluating organizational structure, information systems, finance, and marketing (Font, 2012).

FBO provides an environment conducive for future engineers to develop competencies linked to sustainability (Johnston, 2016; Sánchez-Carracedo et al., 2020). In contrast to the linear model of the value chain (Porter, 1985), the circular economy model (Ellen MacArthur Foundation, 2015) is introduced, proposing the funnel metaphor as a more realistic and nuanced vision of sustainability.

Figure 1

Funnel Metaphor



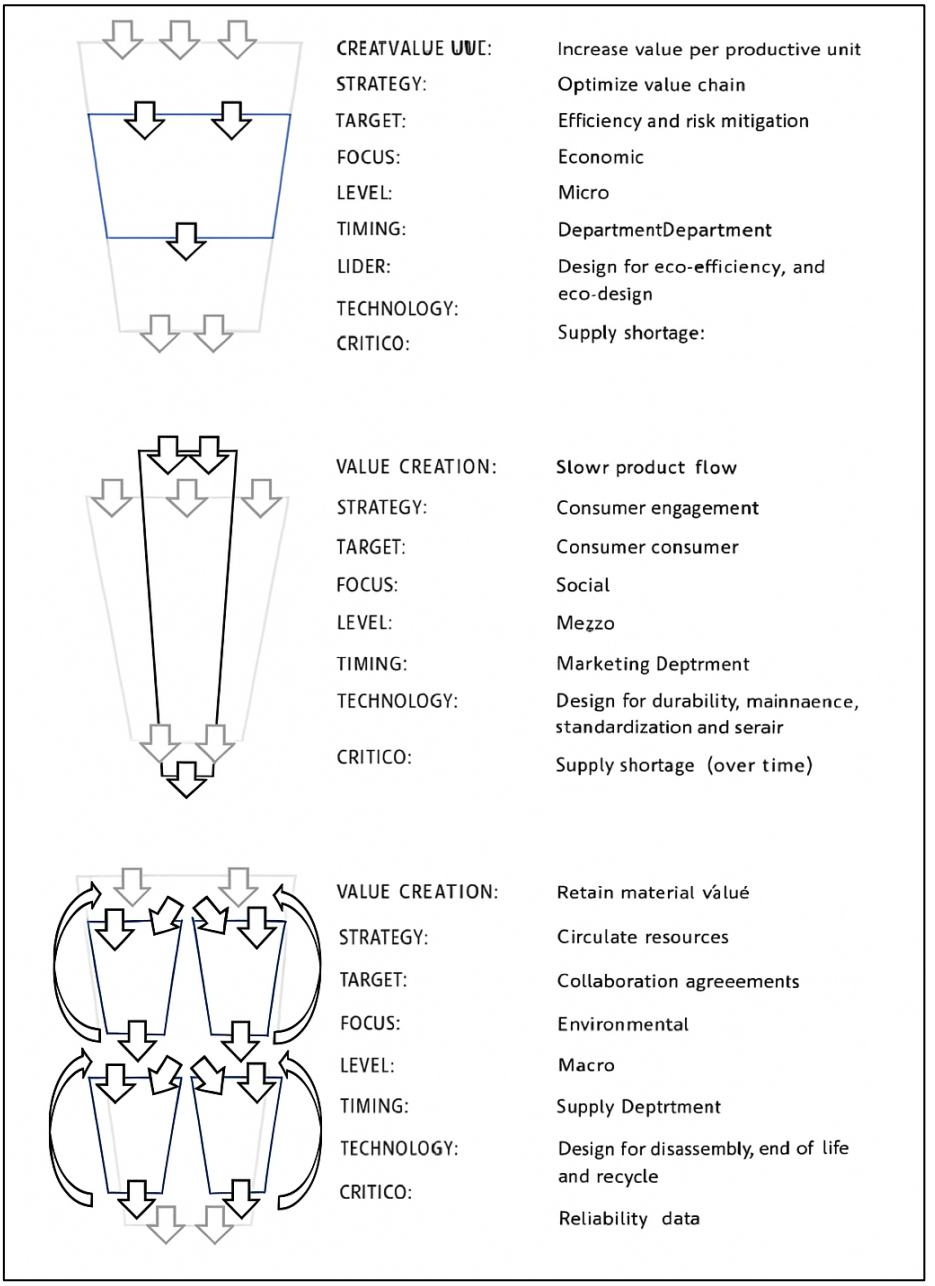
Source: Authors' own elaboration.

Students are presented with the categorization of patterns as a continuous process toward circularity, rather than a fixed state that can be achieved without the use of materials or energy. This perspective aligns with a dynamic and evolutionary approach to sustainability. To illustrate this concept, the three-step configuration of the funnel metaphor is adopted (see Figure 2), which highlights the

progressive nature of circularity and the interconnected strategies necessary for its implementation. This approach has been termed the Pattern Categorization Framework.

Figure 2

Pattern Categorization Framework



Source: Authors' own elaboration.

Note. (1) optimization, (2) preservation, and (3) circularity of resources.

Pattern (1) Optimization seeks to enhance resource efficiency by reducing material consumption and utilizing renewable biomaterials. An efficient value chain is promoted to reduce emissions and waste, applying strategies such as eco-efficiency, lean management, cleaner production, and zero waste. Industrial symbiosis allows waste to be converted into useful inputs, strengthening supply chains by reducing dependence on new materials. Technologies like eco-design and eco-efficiency facilitate more sustainable production, with success measured by resource use efficiency.

Pattern (2) Preservation focuses on extending product lifetimes to increase economic value and reduce the need for new resources. Strategies such as repair, reuse, redistribution, and remanufacturing promote durable products and reduce total cost of ownership, thereby improving quality of life (Ellen MacArthur Foundation, 2015). This approach transforms the relationship with customers, prioritizing functionality over ownership, which positions sustainability as a key factor for reputation and marketing (Accenture Strategy, 2014; Rosa et al., 2019). Technologies such as modular and standardized design support this transition.

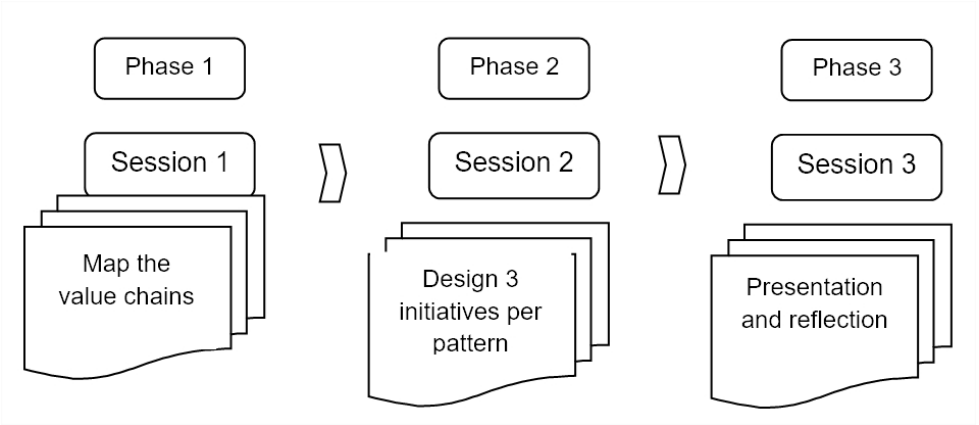
Pattern (3) Circularity aims to minimize value loss by reintegrating waste into new production chains. Strategies such as recycling, upcycling, and downcycling require a systemic approach and reverse logistics networks (Ellen MacArthur Foundation, 2015). The creation of circular networks at both local and global levels is promoted, supported by technologies for traceability, transparency, design for disassembly, and recycling. The availability of reliable data is essential to foster collaboration among stakeholders and achieve more ambitious circular value chains (Hassiotis, 2020).

Results and discussion

The primary outcome of this work is the implementation of an educational activity based on the application of the Pattern Categorization Framework, aimed at identifying and exploring existing opportunities within a company to promote the Sustainable Development Goals (SDGs), particularly Goal 12: Responsible Production and Consumption. This activity yields learning outcomes that include the proposal and design of sustainable initiatives applied to real business contexts. Figure 3 presents a diagram illustrating the development of this activity.

Figure 3

Development of a new activity to promote SDG "Responsible Production and Consumption"



Source: Authors' own elaboration.

The activity begins with a theoretical session addressing the fundamental concepts of sustainability, circular economy, and the Pattern Categorization Framework, complementing the previously scheduled practices in the course. Subsequently, students are asked to represent and describe the funnel metaphor as applied to the selected companies. To do this, they create a map of the flow of material resources, energy, and labor throughout the value chain, illustrating how products traverse the various stages of the life cycle: from production, sales, and distribution to use and, finally, end-of-life management when waste exits the system.

In the next phase, students must design initiatives aligned with the three sustainability patterns discussed in the course: resource optimization, product value preservation, and interconnection of multiple funnels. Resource optimization focuses on reducing dependence on non-renewable materials, improving efficiency, and minimizing waste. Students identify ways for the company to utilize its resources more efficiently, increasing productivity and decreasing environmental impact.

On the other hand, product value preservation aims to slow the flow of resources by extending product lifetimes through strategies such as reuse, repair, remanufacturing, and refurbishment. Students analyze how the company can implement practices that prolong the life of its products, thereby reducing the need to manufacture new goods. Finally, the interconnection of multiple funnels emphasizes the creation of collaborative networks in which resources are recycled and reused within the same or across various value chains, thus strengthening circularity. Students investigate how the company can integrate into these collaborative networks to optimize resource use and close the product life cycle.

Each group must develop three initiatives for each category, presenting them in a structured format that utilizes the attributes defined in the conceptual card for each pattern. These attributes allow for the precise capture of the essential characteristics of each action, such as value generation, initiative objectives, the approach adopted, and the technologies required for implementation.

This framework provides students with a clear and systematic structure to design and evaluate proposals that promote sustainability and circularity in the business realm. The initiatives designed are presented to the other groups, fostering an exchange of ideas and a comparative analysis of the different proposals. This dynamic creates a collaborative learning environment that stimulates critical reflection on the various ways to apply the theoretical concepts discussed in the course.

Regarding course organization, it currently consists of nine sessions, two of which are dedicated to team presentations. A restructuring of the schedule is proposed to distribute the sessions as follows: four sessions for the previously scheduled activities and three for the new pattern analysis activity. Of these last three, one session will be devoted to introducing the basic concepts of circular economy and sustainability, while the other two will allow groups to develop and analyze their initiatives. Of the two sessions dedicated to presentations, one will be reserved for showcasing the previously scheduled activities, and the final session will be exclusively dedicated to presenting the results of this new activity.

The implementation of this methodology reinforces the fundamental role that universities play in training professionals capable of addressing global challenges such as climate change and social inequality. In line with the strategic commitment of the Universitat Politècnica de València (UPV) to integrate the SDGs into its institutional plan, this initiative in the FBO course aims to promote explicit social and environmental commitment among future Data Science engineers. This also responds to the growing demand in the labor market for professionals who, in addition to technical competencies, possess cross-disciplinary skills and a strong sense of social responsibility.

The incorporation of the Pattern Categorization Framework, developed by Esteban-Amaro et al. (2024), represents a significant contribution, as it provides a structured tool that facilitates the practical application of engineering research ideas to real business contexts, with a focus on sustainability and the circular economy. Unlike traditional linear models of the value chain, this activity introduces the circular economy model from the Ellen MacArthur Foundation (2015) and the funnel metaphor, providing a progressive view of circularity and interconnected strategies (optimization, preservation, and circularity).

This approach enables students to understand how to reduce dependence on non-renewable resources, extend product lifetimes, and reintegrate waste into new production chains (Hassiotis, 2020). Furthermore, it highlights the importance of having reliable data to promote collaboration and achieve more ambitious circular value chains, an area where training in Data Science is essential.

This proposal also addresses frequent criticism of higher education institutions for their excessive emphasis on theoretical teaching at the expense of applied learning and the development of functional skills (Direito & Freitas, 2024). By focusing on practical group activities such as PESTEL analysis, SWOT, Value Chain, and now the application of the Pattern Categorization Framework, the FBO course fosters key cross-disciplinary competencies, such as innovation, teamwork, communication, and social and environmental commitment.

The relevance of these "soft" skills is repeatedly emphasized by companies, which perceive a gap in their application by recent graduates. By integrating Social and Environmental Commitment as an essential competency, guided by the SDGs, students are prepared to act with ethics and professional responsibility in the face of current social, environmental, and economic challenges.

Although the study represents a valuable educational intervention, it is essential to recognize its limitations, such as its initial application in a single course and the absence of empirical data on its pedagogical impact. However, the methodological design based on educational action research promotes continuous improvement of educational processes and fosters reflective and experiential learning.

Future research could expand this framework to other courses and educational levels, as well as conduct comparative studies between different universities to assess its versatility and cross-cutting impact on sustainability education. Additionally, it will be crucial to carry out systematic evaluations of the impact of the Pattern Categorization Framework in relation to SDG 12, considering various organizational and cultural contexts, to consolidate and validate these findings.

Conclusions

Data science engineers play a key role in promoting sustainable innovation by using data analysis to optimize decision-making. By analyzing sustainability education in the Data Science degree at UPV and its alignment with institutional strategic objectives, it is believed that strengthening sustainability-oriented learning can contribute to a more ethical professional practice prepared for future challenges.

This study proposes an educational intervention in the course "Fundamentals of Business Organization" by incorporating a practical activity that integrates sustainability into business analysis. This initiative aims to complement students' social skills with the development of social and environmental commitment, fostering an ethical approach to social, economic, and ecological challenges, guided by fundamental values and the Sustainable Development Goals (SDGs), particularly SDG 12: Responsible Production and Consumption. This objective is addressed through the Pattern Categorization Framework presented in this work.

Preliminary results indicate that this framework provides a structured tool that facilitates the practical application of student ideas in real contexts, enhancing their understanding of the impact of sustainability on quality of life, productivity, and economic, social, and environmental development. This approach contributes to training professionals capable of promoting responsible production and consumption practices in organizational settings.

UPV is actively leading the transition toward more sustainable education, aligning its programs with the SDGs and promoting innovative methodologies. Initiatives like the Pattern Categorization Framework not only enhance technical

training but also raise students' social and environmental awareness, solidifying the university's role as a transformative agent.

Among the main limitations of the study is its application in a single course, which restricts its reach to other curricular contexts. Additionally, the lack of empirical data on the implementation prevents a full assessment of its pedagogical impact.

For future research, it is recommended to apply this methodological framework in other courses and educational levels to evaluate its versatility and cross-cutting reach in sustainability education. Furthermore, comparative studies with other universities that have adopted similar practices should be conducted to identify success factors, institutional barriers, and opportunities for improvement. Finally, it is essential to systematically assess the impact of the Pattern Categorization Framework as an educational tool, particularly regarding SDG 12, in various organizational and cultural contexts.

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Declaration of author responsibility

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Sofía Aparisi-Torrijo 3: Data curation, Writing/original draft and Writing, review and editing.
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