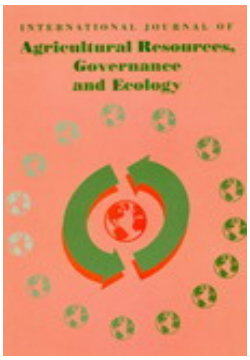

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Delivering bioeconomy through creative learning: Portuguese higher education curricula context

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Abstract: The bioeconomy, also known as the 'economy for life', is crucial in addressing global challenges like climate change and resource scarcity. Higher education institutions must adopt innovative, interdisciplinary, and creative learning approaches to prepare students for sustainable economic growth. This study assessed students' self-perceived knowledge of bioeconomy through creative learning in higher education curricula, evaluating familiarity, value perception, and willingness to learn more. The survey conducted for 1st-year students from economy-related courses in four HEIs in Portugal resulted in 312 valid responses. Results showed no significant association between bioeconomy knowledge and participation in creative projects due to a lack of offers and low awareness. Interestingly, although students are unfamiliar with the bioeconomy concept, they believe in its value and importance. A key aspect involves understanding the perceptions of outcome importance and the skill level that can be achieved. The transformation is vital for training decision-makers capable of supporting sustainability challenges.

Keywords: innovative learning; decision-making; sustainability; education; bioeconomy; transdisciplinary thinking; creative learning; sustainability skills; transformation; interdisciplinary projects; CL4Bio.

JEL codes: M21, M31, O33, Z32.

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1 Introduction

Climate change, land degradation, overpopulation, and food security are critical challenges threatening society and the environment (Torres et al., 2023). In response, the bioeconomy concept has emerged as a promising solution, leading to a growing demand for bioeconomy education (Marcineková et al., 2023). However, the integration of bioeconomy concepts into higher education curricula remains a complex challenge due to the predominance of approaches focused on theoretical learning and the lack of structured methodologies for active student engagement (Pubule et al., 2020; Paris et al., 2023). While higher education institutions (HEIs) hold a fundamental position in advancing sustainable development, particularly in relation to the Sustainable Development Goals (SDGs) outlined in the Incheon Declaration, many still struggle to transition from traditional teaching methods to more innovative, interdisciplinary approaches that reflect the dynamic nature of the bioeconomy (Urmetzer et al., 2020). However, despite this growing interest, the existing guidelines concerning the SDGs tend to be predominantly policy-oriented and lack specific, actionable recommendations. Consequently, incorporating education for sustainable development (ESD) into higher education

curricula has progressed very slowly. Nonetheless, the specific strategies HE should adopt in this endeavour remain debatable (Cardiff et al., 2024; Drejerska, 2024; Marcellus et al., 2024). Bioeconomy helps to solve societal, environmental, and economic issues, including climate change, resource scarcity, and pollution. Additionally, it supports sustainable development, creates job opportunities, and improves the quality of life, especially for marginalised groups such as rural citizens and minorities.

In this context, Portugal presents an interesting case study because, unlike countries such as Germany and Finland, which have well-established bioeconomy strategies (BOR, 2015), Portugal is still in an early stage of bioeconomy development, with slower integration into education and industry (Figueiredo et al., 2023). Recent studies indicate that Portuguese students have varied levels of awareness about bioeconomy-related topics, with a predominant focus on environmental aspects rather than economic and social dimensions (Figueiredo et al., 2023). Understanding how creative learning strategies can bridge these knowledge gaps is crucial for developing more effective educational approaches.

The study is focused on the creative learning experience and bioeconomy perception by 1st-year students from economy-related courses in four HEIs in Portugal. Applying this method aims to provide university decision-makers with insights that can help improve the quality of their study programs by integrating innovative learning strategies and tools, thereby ensuring that initiatives are focused on achieving the most significant and sustainable results. Section 2 reviews the literature and describes the current situation to develop the concept. Section 3 describes the methodology and results of the work, where key findings include familiarity, value perception, importance, willingness to learn, and engagement with creative projects. In Section 4, the discussion focuses on the main aspects highlighted throughout the study. Section 5 concludes the study, summarising its main contributions and providing insights into future decision-making, emphasising community engagement, creative approaches, and practical applications that will foster a generation capable of addressing sustainability challenges effectively. This comprehensive analysis illustrates the urgent need for HEIs in Portugal to systematically integrate bioeconomy concepts into their curricula while promoting active and creative learning experiences among students.

2 Theoretical background

2.1 Bioeconomy

The bioeconomy, which promotes the sustainable use of renewable biological resources, has grown significantly, becoming a key pillar of global efforts to tackle pressing issues like climate change, energy security, and food supply (D'Adamo et al., 2022; European Commission, 2020). The European Commission characterises the bioeconomy as an economic system that relies on renewable resources derived from terrestrial and aquatic environments. This includes various elements such as crops, forests, fish, livestock, and microorganisms, which are utilised to generate food, energy, and various materials. This definition is closely aligned with the European Union's innovation strategies and its goal of fostering a 'knowledge-based economy' (European Union, 2000; European Commission, 2020).

The bioeconomy concept has evolved from two primary perspectives: resource substitution and biotechnology innovation. The former scope on replacing finite fossil resources with renewable biological alternatives, while the latter focuses on leveraging advances in biological sciences to drive economic activity and deliver societal benefits, such as new biofuels, pharmaceuticals, and bioplastics (White House, 2012; BOR, 2015). This shift demonstrates how bioeconomy policies have evolved from merely replacing resources to embracing a more innovation-driven model, actively responding to technological advancements in the use of biological resources (Chkoniya et al., 2021).

Countries such as Germany, Finland, Austria, and Norway have established bioeconomy policies, each shaped by their national priorities and available resources (BOR, 2015; Federal Ministry of Education and Research, 2010). In the US, the bioeconomy is viewed as a driver of innovation, spanning multiple sectors and fostering advancements in health, agriculture, and energy (White House, 2012). Jovanovic and Rousseau (2005) describe the bioeconomy as having three core characteristics: pervasiveness – the capacity to impact a wide range of sectors; improvement – reducing costs for users; and innovation spawning – the ability to create new products and services. This perspective underscores the broad, transformative potential of the bioeconomy, as it increasingly touches various industrial and scientific domains.

The bioeconomy presents extensive environmental, economic, and social benefits. Promoting circular economy practices and reducing dependence on fossil resources supports sustainable resource management and reduces greenhouse gas emissions (D'Adamo et al., 2022; Moura et al., 2023). Economically, it stimulates job creation and drives innovation across agriculture, forestry, biotechnology, and waste management (European Commission, 2012). Socially, the bioeconomy contributes to food security and rural development by supporting sustainable agricultural practices and innovations in bioproducts (Aguilar et al., 2020; Drejerska, 2024; Tiatité, 2023).

Innovation remains a central driver of the bioeconomy, especially in fields like biotechnology, genomics, and synthetic biology, which are opening new possibilities for sustainable bioproducts (Bröring et al., 2020). This innovation-driven approach is crucial for broader shifts in resource use, providing bio-based alternatives in areas such as energy and manufacturing. The growing scarcity of resources and the urgent need for climate resilience also fuel the expansion of the bioeconomy, highlighting its role in developing solutions like biofuels, bioplastics, and biomaterials (Wesseler and von Braun, 2017).

Realising the full potential of the bioeconomy requires supportive policies that foster research and development, sustainable production practices, and the integration of bio-based products into mainstream markets. National and international policy frameworks must align bioeconomy strategies with global sustainability goals (SDGs) (D'Adamo et al., 2022). However, challenges persist in standardising metrics to measure the growth of the bioeconomy and balancing food security with the increasing demand for bio-based products (Lewandowski et al., 2018).

2.2 Higher education curriculum

The expression 'knowledge-based' aligned with the then-dominant innovation policy of the European Union (EU). At a Lisbon meeting in 2000, the European Council undertook to develop the world's most dynamic and competitive knowledge-based economy (European Union, 2000).

Several authors analyse the evolving undergraduate curriculum in the third decade of the 21st century. Key change vectors influencing the undergraduate curriculum are divided into three main groups (Cardiff et al., 2024; Conroy et al., 2024; Mair and Druckman, 2023; Krause, 2020):

a *External forces affecting curriculum:*
   - *Universalisation:* The trend toward standardising educational practices across different regions and institutions.
   - *National policies and legislative frameworks:* Government-directed initiatives and legal influences are shaping curricular priorities.
   - *Technological influence:* Technology acts both as a disruptor, changing traditional teaching methods, and as an enabler, facilitating new learning opportunities.

b *Historical context and familiarity:* While some socio-political, economic, and geopolitical forces driving change are well known and have persisted over time, they continue to reshape curricula today.

c *Recent influential factors (past decade):*
   - *Disruptive technology:* Advances in technology have revolutionised how education is delivered and accessed.
   - *Micro-credentialing:* Emerging practices in curriculum design that offer smaller, focused credentials, catering to diverse learner needs and preferences.
   - *Changing expectations:* Evolving societal and student expectations regarding what constitutes a relevant and effective undergraduate education.

This analysis emphasises the need for adaptive curriculum strategies to meet higher education's multifaceted changes and challenges.

2.3 Bioeconomy in higher education

In addressing key global challenges such as climate change, resource scarcity, and sustainable development, the bioeconomy necessitates a fundamental shift in educational strategies to foster the skills essential for a sustainable and circular economy. Higher education plays a pivotal role in this transformation, offering the intellectual foundation needed to shape policies and practices. Successfully implementing bioeconomy principles requires a holistic approach that considers the complex interactions between economic, social, cultural, political, organisational, and technical systems (Chkoniya et al., 2024; Leach et al., 2010; Schlaile et al., 2017). Educational initiatives are therefore vital, encouraging individuals to adopt sustainable behaviours and perspectives aligned with SDG 4 on inclusive, equitable, and lifelong learning (United Nations, 2015).

HEIs are expanding bioeconomy programs to include essential skills for the bio-based economy. Pubule et al. (2020) identified critical competencies, such as transdisciplinary thinking, systems thinking, and sustainable innovation, in bioeconomy master's programs across Europe. These programs emphasise both interdisciplinary and transdisciplinary skills to foster adaptive, knowledge-based economies. Pubule et al. (2020) further suggest that these programs should incorporate additional competencies, such as normative, strategic, and interpersonal skills, to better prepare graduates for leadership roles in

sustainable bioeconomy sectors. Similarly, Urmetzer et al. (2020) highlight the transformative knowledge conveyed in European graduate bioeconomy programs, which focus on communication skills but could benefit from a stronger emphasis on governance, enabling students to understand and influence political structures more effectively.

The importance of interdisciplinary education in the bioeconomy is well recognised (Baptista et al., 2021; Pubule et al., 2020), particularly in creating a framework that integrates social and biological sciences to foster bioeconomic development (Sacchi et al., 2021). Effective bioeconomy programs must go beyond traditional educational models and incorporate transformative learning approaches that encourage proactive engagement with sustainability and governance (Urmetzer et al., 2020). Paris et al. (2023) reviewed educational methodologies across the European Union, finding that higher education approaches are predominantly lecture-based, supplemented by some experiential methods. In vocational education and training (VET), a blend of academic and practical techniques supports the development of industry-specific skills, demonstrating efforts to adapt bioeconomy training to meet real-world needs (Chkoniya, 2021).

Several bioeconomy-specific study programs have emerged in recent years. The University of Hohenheim notably launched Europe's inaugural Bioeconomy degree program (MSc Bioeconomy). Other significant programs include the MSc Biobased Sciences offered at Wageningen University and the MSc Biobased Materials available at Maastricht University (Lewandowski et al., 2018). These programs focus on the entire bio-based value chain and consider bioeconomic developments' ecological, social, and economic impacts. Their goal is to prepare professionals capable of identifying innovation opportunities through multi- and interdisciplinary perspectives, incorporating diverse knowledge sources, and fostering skills through interdisciplinary problem-based group activities.

2.4 Bioeconomy in Portuguese higher education

The development of the bioeconomy in Portugal is still in its early stages, marked by slow but promising growth. Helpman and Trajtenberg (1996) describe the Portuguese bioeconomy as a relatively new general-purpose technology system that has gradually emerged over recent years. Unlike more established European bioeconomy sectors, the Portuguese context remains nascent, with technological advancements proceeding cautiously. Nelson et al. (2004) further emphasise that the Portuguese bioeconomy can be seen as a social construct, with its technical merits still open to debate. This points to broader uncertainties surrounding the bioeconomy in Portugal and varying levels of engagement among key stakeholders, including industry, academia, and government.

Edquist (2005) highlights that the successful development of the bioeconomy in Portugal depends largely on the cultural attitudes of both consumers and policymakers. A conducive economic environment will only materialise if there is adequate support from the political landscape and demand for bioeconomic products by consumers. Thus, the flourishing of the bioeconomy in Portugal is closely linked to the cultural and institutional willingness to drive innovation and investment in bio-based solutions.

Figueiredo et al. (2023) evaluated the proficiency in understanding biotechnological approaches to environmental sustainability in Portugal, emphasising issues such as air quality, water contamination, climate change, and energy resources. A survey of 471

individuals aged between 15 and 78 revealed that older respondents (over 65) displayed lower literacy levels and greater uncertainty. Higher literacy levels were found regarding global warming and water pollution, while air pollution and energy resources were less understood, suggesting a correlation between public awareness and media coverage. These findings highlight the importance of education and awareness campaigns to bridge the knowledge gaps within the Portuguese population, particularly among older citizens and in areas with lower visibility, such as air pollution and energy resources. This underlines a potential role for HEIs in Portugal to develop dedicated bioeconomy courses that promote awareness and foster a culture of innovation in sustainability-focused technologies.

HEIs in Portugal are vital in addressing the challenges identified by these studies. By integrating bioeconomy concepts into academic curricula and fostering interdisciplinary research and learning, universities can support the development of a knowledge-based bioeconomy tailored to Portugal's specific cultural and economic context. Efforts to create targeted bioeconomy educational programs could help shape consumer attitudes, increase literacy in biotechnological solutions, and prepare a new generation of professionals capable of advancing the bioeconomy in Portugal.

2.5 Bioeconomy and creative learning approaches

The bioeconomy, which relies on renewable biological resources to produce goods and services, is increasingly important for sustainable development. HEIs have a critical role in preparing students for this transition by employing innovative, interdisciplinary, and creative learning approaches. Onpraphai et al. (2021) emphasise the need for a shift towards more integrated and holistic educational approaches, including community-based learning that involves both practical and online engagement. This transformation is vital for training a workforce capable of supporting the sustainable production of biomaterials, food, wood, and energy while addressing ecological and socio-economic challenges.

Creativity also plays an essential role in sustainability education. Sanz-Hernández and Covaleda (2021) illustrate this by using mail art as an educational tool that connects young artists with sustainability challenges, promoting creative engagement and collective action. Creative methods, such as arts-based learning, enable students to express their visions of sustainability, enhancing their understanding of complex social, ecological, and economic issues. This approach complements the technical aspects of bioeconomy education by fostering innovative and ethical thinking.

In addition to creative approaches, bioeconomy education requires experiential and problem-based learning. Paris et al. (2023) found that bioeconomy education practices in the EU often combine traditional lectures with experiential components, helping students integrate theoretical knowledge with practical applications. For instance, VET programs emphasise combining academic learning with practical skills, preparing students for real-world scenarios.

Developing a robust bioeconomy workforce also requires integrating experiential learning opportunities. Aurand (2022) highlights the importance of practical experiences such as internships, innovation competitions, and interdisciplinary education. Such initiatives equip students with technical skills and foster creativity and entrepreneurial thinking, which are vital for driving innovation in the bioeconomy.

3 Methodology

A survey evaluated HEI students' awareness of bioeconomy and creative learning. The data gathered from this survey aimed to measure students' openness to engaging with new courses and learning methodologies in the context of the bioeconomy. The survey was implemented using LimeSurvey, a free and open-source online survey platform (Limesurvey GmbH, 2019). Institutional emails were dispatched to target students enrolled at Portuguese universities participating in the Cl4Bio project, inviting them to participate via a link to the designated survey webpage.

The survey comprised a total of 22 questions, which were presented sequentially rather than simultaneously during the completion process. The final eight questions were designed to gather information regarding the students' educational backgrounds, levels of achievement, and demographic details. The preceding ten questions focused on assessing the student's knowledge of bioeconomy and its perceived significance and willingness to engage in specialised courses; three of these questions utilised a five-point Likert scale. The remaining questions aimed to explore aspects of creative learning to gain a deeper understanding of the perspectives held by the respondents.

Quantitative data were analysed utilising the Statistical Package for Social Sciences IBM SPSS Statistics (Version 27). Qualitative data were represented through numerical values and percentages. Associations were determined at a 95% confidence interval, with a significance threshold established at $\rho < 0.05$ to assess the strength of the evidence. Grammarly (2024) is used to improve the readability and language of the work.

4 Results

A total of 411 valid responses were received, of which 314 were from HEI students. Two were removed because the respondents were minors. The survey conducted for 1st-year students from economy-related courses in four HEIs in Portugal resulted in 312 valid responses.

In demographic terms, there is a slight preponderance of people identifying as female (173) compared to male (138); one respondent preferred not to identify in this variable.

There is an intense concentration of respondents aged between 18 and 24 years old (244), with a successive decrease in all other age groups [35 (25 to 34), 18 (35 to 44), 13 (45 to 54), 2 (55 to 64)]. This aligns with most undergraduate students (202); others have already completed their undergraduate degrees.

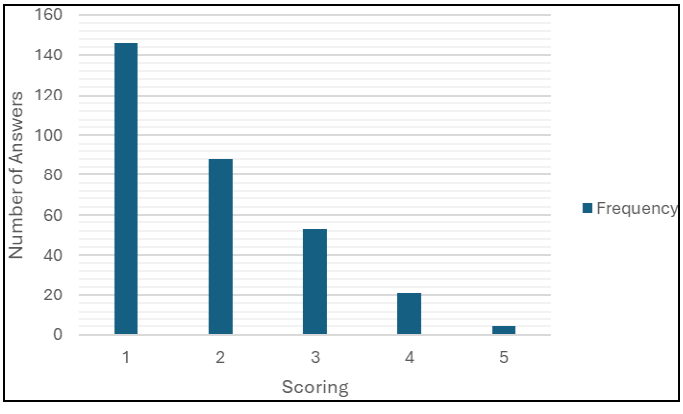
The study aimed to assess the students' self-perceived knowledge about bioeconomy through creative learning in the higher education curricula context and evaluate familiarity, value perception, and given importance, together with their willingness to learn more about the subject with innovative methodologies.

4.1 Familiarity with bioeconomy

In the present research, we consider the concept of familiarity by focusing on stimuli that an individual has encountered in a direct, tangible, and personal manner (Qin and Northoff, 2011). Most respondents (62.8%) claim no knowledge about bioeconomy, meaning only 37.2% (116) state they know the concept.

Therefore, it is unsurprising that familiarity with the concept could be much higher (Figure 1).

Figure 1 Familiarity with the concept of bioeconomy (see online version for colours)



Notes: This graph shows the distribution of respondents' familiarity with the concept of bioeconomy. The Y-axis represents the number of answers, and the X-axis represents the scoring scale: 1 (completely unfamiliar), 2 (not familiar), 3 (neutral), 4 (moderately familiar), and 5 (completely familiar). Most respondents are completely unfamiliar with the concept.

As shown in Table 1, almost 50% claim to have no familiarity with the bioeconomy, but 92% are not familiar with the concept, and 17.00% choose the neutral answer. Only 8% (100% – 92%) are familiar (6.7% moderately familiar with the concept + 1.3% completely familiar with the concept).

Table 1 Familiarity frequency (absolute, percent, and cumulative)

		Frequency	*Percent*	*Valid percent*	*Cumulative percent*
Valid	1	146	46.8	46.8	46.8
	2	88	28.2	28.2	75.0
	3	53	17.0	17.0	*92.0*
	4	21	6.7	*6.7*	98.7
	5	4	1.3	*1.3*	100.0
Total		312	100.0	100.0	

When asked in the open question what the first word they associate with the bioeconomy, the majority answered sustainability (32%), followed by economy (17%), biodiversity (16%), environment (10%), sustainable economy (8%), circular economy (8%), eco-friendly (6%) with 3% indicating other suggestions. To visually highlight recurring words that were meaningful to the participants, a 'word cloud' was created (Figure 2).

4.2 Value perception and importance

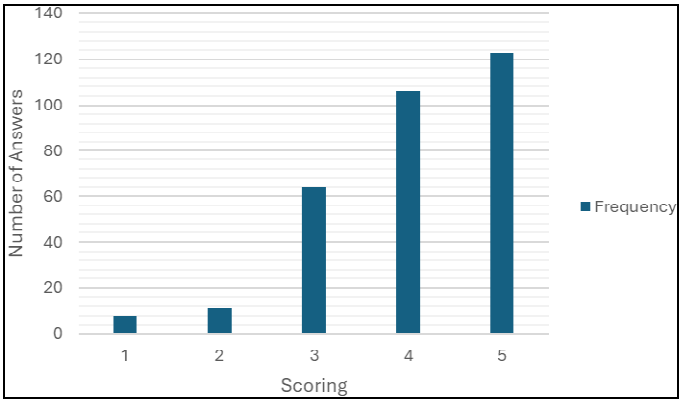
Key aspects involve understanding the perceptions of outcome importance and the skill level that can be achieved (Drejerska, 2024), and how students value them. Perceived

value involves mentally weighing up the advantages and disadvantages of a particular choice or option (Iskandar et al., 2024). Despite the respondent's lack of knowledge about the bioeconomy, they recognise its importance (Figure 3) and worth (Figure 4).

Figure 2 Word cloud based on participant quotations related to associations with the bioeconomy (see online version for colours)

Source: Produced in WordClouds.com

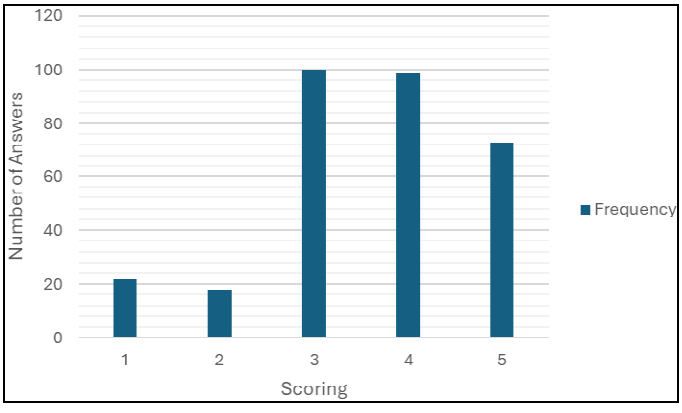
Figure 3 Importance level of bioeconomy (see online version for colours)



Notes: This graph shows the distribution of respondents' views on the importance of bioeconomy. The Y-axis represents the number of answers, and the X-axis represents the scoring scale: 1 (not important at all), 2 (slightly important), 3 (neutral), 4 (important), and 5 (very important). Most respondents consider bioeconomy to be very important.

More than half of the respondents (51.5%) believe in the value of the bioeconomy (Table 2) and 72.4% think it is important (32.7%) or very important (39.7%). Perhaps for this reason, 47.8% of respondents show a willingness (desire) to know more about the subject (Table 3).

Figure 4 Perception of bioeconomy value (see online version for colours)



Notes: This graph shows the distribution of respondents' perceptions of the value of bioeconomy. The Y-axis represents the number of answers, and the X-axis represents the scoring scale: 1 (perceives no value at all), 2 (perceives almost no value), 3 (neutral), 4 (perceives some value), and 5 (perceives a lot of value). Most respondents perceive some to a lot of value in the bioeconomy.

Table 2 Value perception frequency (absolute, percent, and cumulative)

Scoring	*Frequency*	*Percent*	*Valid percent*	*Cumulative percent*
1	22	7.1	7.1	7.1
2	18	5.8	5.8	12.8
3	100	32.1	32.1	44.9
4	99	31.7	31.7	76.6
5	73	23.4	23.4	100.0
Total	312	100.0	100.0	

When students were asked, "how do you prefer to learn new concepts and ideas?" almost 60% mentioned practical activities and projects, followed by lecture-style classes (19.3%), group discussions, and collaborations (18.1%), noticing that fewer popular methods with 0.3% each are the individual projects and lecture style to explain the topic but afterwards discussing or doing exercises with others from class.

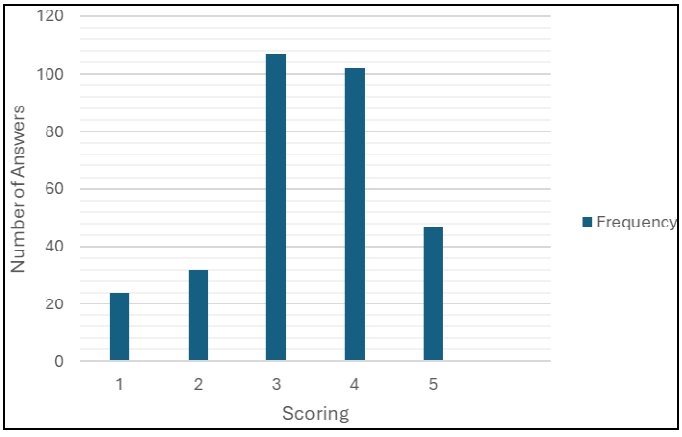
Noticing that 71.3% consider it important (32.12%) or very important (39%) to incorporate creative learning techniques into curricular units taught at HEIs.

4.3 Willingness to learn more

Willingness, a common method within contingent valuation, estimates benefits derived from alterations in students' utility concerning non-tradable concepts, utilising either stated or revealed preferences (Paudel et al., 2020).

Although there are bioeconomy-related activities available, participation is not very significant (Table 4). Only 16 participated in projects, and 26 participated in training activities. Workshops are the most popular bioeconomy-related activity, with 296 stating that they have already participated once.

Figure 5 Willingness to engage in bioeconomy activities (see online version for colours)



Notes: This graph shows the distribution of respondents' willingness to engage in bioeconomy activities. The Y-axis represents the number of answers, and the X-axis represents the scoring scale: 1 (not willing at all), 2 (not willing), 3 (neutral), 4 (moderately willing), and 5 (very willing). Most respondents are neutral to moderately willing to engage in bioeconomy activities.

Table 3 Willingness frequency (absolute, percent, and cumulative)

Scoring	*Frequency*	*Percent*	*Valid percent*	*Cumulative percent*
1	24	7.7	7.7	7.7
2	32	10.3	10.3	17.9
3	107	34.3	34.3	52.2
4	102	32.7	32.7	84.9
5	47	15.1	15.1	100.0
Total	312	100.0	100.0	

Table 4 Creative courses (related to bioeconomy) participation (0 – no participation; 1 – participation)

		Training	*Workshops*	*Project*
Creative courses	0	286	217	296
	1	26	72	16
Total		312	289	312

When asked about the topics or areas they would be interested in exploring further in the context of bioeconomic education, students demonstrated a pragmatic approach and highlighted several key areas of interest. These can be grouped into the following categories:

1 *Bioeconomy applications and industry integration:*
   - Bioeconomy applied to different types of companies, industries, and services.
   - Processes for implementing renewable biological resources and differences between conventional and bioeconomic business models.

- How individuals and companies can act in a 'bioeconomic' way, and legislative issues to promote this transition.
- The importance of bioeconomy for global sustainability.

2 *Natural resources, energy, and agriculture:*
- Use of natural resources for energy, agriculture, and forestry.
- Development of sustainable technologies, carbon footprint reduction, and waste management.
- How new technologies can contribute to sustainable energy production in the bioeconomy.

3 *Sustainability and circular economy:*
- The importance of the bioeconomy for the world and its relationship with sustainability.
- Circular economy, sustainable tourism, and renewable energy sources.
- Reusing materials and products for greater sustainability.
- Reuse of food waste and plastic recycling to reduce the carbon footprint.

4 *Practical applications and everyday life:*
- Practical applications of the bioeconomy in everyday life, including in relation to the oceans, biosciences, and biodiversity.
- What practical actions can companies and individuals take to be more 'bioeconomic' daily.

5 *Social, economic, and environmental impact:*
- The social, economic, and environmental impact of the bioeconomy.
- Sustainability in organisations and the impact of economic change.
- Feelings about sustainability and environmentally friendly actions.

6 *Education and critical analysis:*
- Critical analysis of news and articles on sustainability.
- Education on how to use natural resources more sustainably.
- What is the impact of the bioeconomy on the circular economy and the management of natural resources.

This indicates that HEIs must adopt curricula context for all stakeholders by adjusting students' willingness to learn to meet the demands of society for sustainable development with the help of bioeconomy. Namely, focusing on the following questions:

1 How the bioeconomy encompasses biological resources for energy, agriculture, and industry. Explaining in what ways it is vital for global sustainability, as it promotes efficient natural resource utilisation, ensuring a harmonious relationship with the environment. This sector's significance is highlighted through its support in mitigating climate change, enhancing biodiversity, and fostering economic resilience.

2 What are the practical applications of the bioeconomy that can be observed in daily life, such as sustainable practices in oceans, biosciences, and overall biodiversity conservation? Individuals and companies can adopt bioeconomic strategies by implementing renewable resources, reducing carbon footprints, managing waste effectively, and embracing the principles of a circular economy.

3 Legislative measures are vital in advancing the transition to sustainable technologies that reduce carbon footprints. A thorough analysis of current news and articles reveals diverse perspectives on the effectiveness and challenges of sustainability initiatives.

4 In what way does the bioeconomy contribute significantly to economic vitality, social equity, and ecological balance, making it an imperative focus for future global growth strategies as organisations seek impactful changes amid evolving economic landscapes?

Furthermore, educational efforts are essential in teaching sustainable resource use, while awareness around food waste reuse and plastic recycling bolsters environmental responsibility. The shift towards sustainable tourism and renewable energy sources exemplifies the synergy between societal progress and environmental stewardship. This conclusion aligns with many authors highlighting that transforming practices depends on collaborative learning among actors, fostering innovative approaches (Milou and Del Corso, 2023).

4.4 Hypothesis testing

Hypothesis tests were carried out to better understand the relationships established.

H10 People who know what the bioeconomy is value it like people who do not know.

H11 People who know what the bioeconomy is value it more than people who are unaware of it

H20 People who know what the bioeconomy is give it the same importance as people who do not know it.

H21 People who know what the bioeconomy is give it more importance than people who do not know it

H30 People who know what the bioeconomy is have the same willingness to learn more about the bioeconomy as people who are unaware of it.

H31 People who know what the bioeconomy is have more willingness to learn more about the bioeconomy than people who are unaware of it

No empirical evidence shows a statistically significant difference in the importance attributed and the values of those who know and those who do not know the concept (Table 5). However, it is interesting to note that those who know the concept are willing to know more, indicating a higher interest in further learning among those already familiar with it. So, the first effort to make the concept meaningful is the most important and decisive. Communicating the meaning of bioeconomy better is crucial, as people who know the concept will be more receptive to more information later. Communication plans should be more appropriate in the initial phase of the educational process.

Table 5 Bioeconomy hypothesis tests

		Levene's test for equality of variances		*t*	*df*	*Significance*	
		F	*Sig.*			*One-sided p*	*Two-sided p*
Willingness	Equal variances assumed	5.576	0.019	–2.460	310	0.007	0.014
	Equal variances are not assumed			–2.376	216.155	0.009	0.018
Value	Equal variances assumed	1.006	0.317	–1.148	310	0.126	0.252
	Equal variances are not assumed			–1.127	227.793	0.131	0.261
Importance	Equal variances assumed	0.112	0.738	–1.299	310	0.097	0.195
	Equal variances are not assumed			–1.302	243.198	0.097	0.194

Hypothesis tests were also carried out regarding gender identity.

H40 Familiarity is similar between men and women.

H41 Familiarity is different between men and women.

H50 Willingness to know more is similar between men and women.

H51 Willingness to know more is different between men and women.

H60 The importance attributed is similar between men and women.

H61 The importance attributed is different between men and women.

Table 6 Group statistics regarding gender

	Gender	*N*	*Mean*	*Std. deviation*	*Std. error mean*	*Cohen's d*
Willingness	0	138	3.26	1.155	0.098	–0.18
	1	173	3.46	1.048	0.080	
Value	0	138	3.42	1.164	0.099	–0.27
	1	173	3.72	1.069	0.081	
Importance	0	138	3.87	0.980	0.083	–0.33
	1	173	4.19	0.948	0.072	

At this point, women are more familiar with bioeconomy, attribute more importance to it, and are willing to know more than men (statistically significant difference). However, considering Cohen's, the effect size is small (Cohen, 2013) (Table 6) but statistically significant (Table 7). It is interesting to note that women, on average, score the importance above 4, that is, markedly positive. All other variables are only slightly positive.

H70 There is an association between knowledge in bioeconomy and participation in creative projects.

H71 There is no association between knowledge of bioeconomy and participation in creative projects.

Table 7 Gender hypothesis tests

		Levene's test for equality of variances		*t*	*df*	*Significance*	
		F	*Sig.*			*One-sided p*	*Two-sided p*
Familiarity	Equal variances assumed	3.812	0.052	2.270	309	0.012	0.024
	Equal variances are not assumed			2.214	258.813	0.014	0.028
Willingness	Equal variances assumed	1.416	0.235	–1.564	309	0.059	0.119
	Equal variances are not assumed			–1.547	279.956	0.061	0.123
Importance	Equal variances assumed	0.043	0.835	–2.923	309	0.002	0.004
	Equal variances are not assumed			–2.912	289.433	0.002	0.004

Table 8 Cross tabulation (knowledge and creative courses)

Count		*Creative courses*		*Total*
		0.00	*1.00*	
Knowledge	0	134	62	196
	1	72	44	116
Total		206	106	312

Table 9 Association tests between knowledge and creative courses

	Value	*df*	*Asymptotic significance (two-sided)*
Pearson chi-square	1.289[a]	1	0.256
Continuity correction	1.023	1	0.312
Likelihood ratio	1.280	1	0.258
N of valid cases	312		

Notes: [a]0 cells (0.0%) have expected count less than 5. The minimum expected count is 39.41.

Of the 196 respondents who reported that they are not familiar with the concept of bioeconomy, 62 (31.63%) participated in creative projects, and 134 (68.37%) did not participate; of the 116 who claim to know, 44 (37.93%) claim to have participated in creative projects and 72 (62.07%) did not (Table 8). Unfortunately, the largest group does not know about bioeconomy and does not participate in creative courses about it (134 in

312), which suggests a possible reinforcement mechanism between lack of knowledge and lack of participation, but further research is needed to establish causality.

All tests are in the same line (Table 9). Considering the Pearson chi-square result, the p-value (0.532) is greater than 0.05, indicating insufficient evidence to reject the null hypothesis. Therefore, there is no significant association between the variables of knowledge and creative course participation.

Continuity correction is an adjustment for chi-square testing in 2 × 2 tables (which is the case). The p-value (0.614) is also greater than 0.05, reinforcing the conclusion that no significant association exists. The same goes for likelihood ratio (an alternative to Pearson's chi-square), as the p-value (0.531) is greater than 0.05, indicating no significant association.

All tests indicate no statistically significant association between knowing the concept of bioeconomy and participating in creative projects. The p-value in all tests is greater than 0.05, meaning we cannot reject the null hypothesis that there is no association between the variables.

5 Discussion

The bioeconomy, often called the 'economy for life', presents a significant global challenge that requires a fundamental transformation in educational strategies to develop the skills necessary for sustainable economic and societal development. In this context, when participants were asked to identify the first word associated with the bioeconomy, the most common responses were sustainability (32%), followed by economy (17%), biodiversity (16%), environment (10%), sustainable economy (8%), circular economy (8%), and eco-friendly (6%). A small proportion (3%) provided other responses. These findings align with previous research by Výbošťok et al. (2022) and Niewiadomski et al. (2023), emphasising the strong connection between the bioeconomy, sustainability, and the circular economy.

Notably, more than half of the students recognised the bioeconomy's value, with 72% acknowledging its importance. Interestingly, although many students were unfamiliar with the bioeconomy concept, they still saw its potential significance (Fiore et al., 2024). This finding resonates with the work of Ribeiro et al. (2024), who similarly found that, despite low levels of familiarity, students recognised the bioeconomy's potential for environmental and economic improvements. Similarly, Bröring et al. (2020) observed that while students acknowledge the relevance of the bioeconomy, their limited exposure to structured educational programs and practical applications prevents them from fully grasping its complexity and transformative potential.

One notable demographic difference in familiarity with the bioeconomy emerged: women exhibited a higher level of awareness (Table 7), assigned greater importance to the subject, and expressed a stronger desire to learn more than their male counterparts. This gender-based disparity mirrors findings reported by Ribeiro et al. (2024). Nearly 48% of respondents desired more knowledge on the topic, with more interest focusing on the practical application of bioeconomic principles in various industries and integrating sustainability concepts into real-world practices. This finding aligns with research by Tomazini et al. (2024), who found similar trends among Brazilian university students,

underscoring a growing interest in bridging theoretical knowledge with practical applications.

Additionally, nearly 60% of students preferred practical activities and projects as their favoured method of learning, with over 70% emphasising the importance of integrating creative learning techniques into curricula at HEIs. Despite these preferences, the study found no statistically significant correlation between the concept of bioeconomy and participation in creative projects (Table 9). This could be attributed to the limited availability of such opportunities and a general lack of exposure to innovative teaching methodologies, as Pink et al. (2024) noted in their study of European universities. D'Adamo et al. (2022) also highlighted similar challenges, pointing out that although awareness of the bioeconomy is increasing, its practical implementation in HEIs remains hindered by structural barriers, such as a lack of interdisciplinary approaches and insufficient integration of creative teaching methods.

An intriguing aspect of this study is that many students still recognise its value and importance despite their unfamiliarity with the bioeconomy. Almost half of the respondents expressed interest in further exploring the topic, particularly with respect to its application to various industries and practical sustainability implementation that aligns with the needs and mindset of contemporary society.

While this study focuses on Portugal, future research will extend to other countries using the same survey methodology. Comparative results will provide a more comprehensive understanding of global perceptions surrounding the bioeconomy. Special attention will be given to developing agricultural economies and the transition to renewable energy sources, which are closely linked to the sustainable management of natural resources. Furthermore, future research will delve into the economic processes within the bioeconomy, comparing sustainable bioeconomic practices to less sustainable alternatives. The reuse of materials and products aimed at promoting sustainability and environmental protection will also be a central focus. Noticing that some students, though unfamiliar with the concept, expressed curiosity about the bioeconomy and a desire to understand it better, highlights the importance of expanding educational efforts in this area.

6 Conclusions

This paper explores how creative learning strategies can be instrumental in delivering bioeconomy education within Portuguese higher education curricula. As the bioeconomy is a relatively new and developing sector in Portugal, its integration into higher education is crucial for preparing students to address sustainability and innovation challenges. Despite its slow growth, the bioeconomy shows great promise, and there is an increasing need to bridge the knowledge gaps through effective educational methods. Integrating creative learning strategies into HEIs' curricula holds the potential to solve this challenge effectively. It can help address the varying levels of engagement among stakeholders and foster the development of essential skills for the bioeconomy, such as transdisciplinary thinking, systems thinking, and sustainable innovation. However, this transformation requires a commitment from HEIs to not only incorporate interdisciplinary projects but also to provide faculty with the necessary training in creative methodologies that facilitate these innovations.

Students in Portugal demonstrate a clear willingness to engage with bioeconomy principles despite limited familiarity with the topic. This willingness, supported by their preference for practical, hands-on learning over traditional lecture-based methods, suggests that HEIs should further adapt their curricula to incorporate these preferences. By introducing interdisciplinary approaches, practical applications, and creative teaching methods, institutions can provide students with the skills and knowledge needed to contribute to the bioeconomy and sustainability goals. Moreover, combining both practical and theoretical engagement, community-based learning is important for creating a workforce capable of supporting sustainable production in the bioeconomy. Creative methods offer students the chance to develop technical skills and entrepreneurial thinking. These methods foster creativity, encourage collective action, and help students better understand the bioeconomy's complex ecological, social, and economic dimensions.

Ultimately, providing bioeconomy education through creative learning strategies is crucial for equipping future decision-makers in Portugal to tackle sustainability challenges. HEIs can play a key role in developing the workforce necessary for decision-making and advancing the bioeconomy by transforming curricula into innovative, interdisciplinary, and creative teaching methods.

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