



Original Research Article

The Role of Scientific Empathy and Learning Preferences in Shaping Innovative and Sustainable Learning in European Higher Education

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ABSTRACT

Understanding learning preferences and empathetic needs remains a key challenge in developing aligned learning strategies in higher education, particularly within science, technology, engineering, arts, and mathematics. The study explores how learning content can address diverse cognitive, metacognitive, and emotional student preferences. It assumes that integrating students' learning preferences can improve the alignment of learning approaches with sustainability- and innovation-oriented education. An empathetic questionnaire was used to examine visual, auditory, hands-on, and emotionally driven learning preferences among students from five European higher education institutions. The results suggest a strong preference for visual and hands-on learning approaches. Subject-specific differences indicate that visual and practical methods are preferred for sustainability topics, whereas auditory and experiential methods are preferred for entrepreneurial learning. The findings highlight the potential importance of empathy-based learning design in developing inclusive, adaptable, and student-centred learning approaches that may better prepare students to address complex sustainability challenges.

KEYWORDS

Tailored learning content design, Scientific empathy, Higher education, Sustainability innovation, Entrepreneurial innovation, Learning preferences.

INTRODUCTION

In the modern educational environment, creating effective, engaging learning content requires an understanding of students' diverse learning preferences and emotional needs. However, science education has traditionally emphasised systemising cognition, often

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overlooking empathising processes that are essential for meaningful learning and student motivation [1]. Empathy, particularly scientific empathy, plays a central role in strengthening these connections and fostering deeper engagement among students, lecturers, and learning materials. Scientific empathy extends beyond general empathy by integrating systematic scientific thinking with empathic understanding, involving both cognitive and emotional processes related to scientific and educational activities. It is usually defined as the process of creatively engaging with scientific problems by becoming deeply involved with the object of research, combining sensitivity, situational interest, scientific imagination, empathetic concern, and empathetic understanding of others [2]. This is especially vital when addressing complex socio-scientific and sustainability-related challenges, as it motivates learners to actively participate in scientific inquiry, fosters multi-perspective thinking, and supports innovative and sustainable knowledge development in Science, Technology, Engineering, Arts and Mathematics (STEAM) education.

Existing research highlights the role of empathy in higher education (HE) settings. For instance, a study aimed at developing a Science Empathy Index (SEI) examined various factors, such as sensitivity, situational interest, scientific imagination, and empathy towards others, that influence a student's engagement and problem-solving competence [1]. The SEI is a strong indicator of the link between scientific skills and creative thinking, underscoring the importance of an innovative and sustainable approach to learning in modern education. Beyond general and domain-specific empathy measures, research has also examined the implications of empathy for professional practice and ethical decision-making. Additionally, the Toronto Empathy Questionnaire (TEQ) [3], which measures general empathy, has been applied in various studies to explore the connection between empathy and professional skills. One such study, conducted among dental students in Romania, found that high empathy has a positive impact on the quality of patient care [2]. Importantly, recent research also indicates that lower levels of empathy, combined with stronger systemising tendencies and a scientific worldview, are associated with a greater acceptance of ethically questionable scientific practices, highlighting that empathy plays a crucial role not only in engagement and learning but also in responsible and ethical decision-making in scientific contexts [4]. Recent studies in undergraduate education show that effective scientific communication requires an empathetic, audience-centered approach rather than a knowledge-deficit model. Empathy-based activities, such as role play and active listening, enhance scientific literacy and support the development of socially responsible scientists [5].

Further research on the role of empathy in education highlights the significance of teacher empathy in student engagement. Studies show that students learn better and have more positive perceptions when lecturers display empathy and strive for more meaningful relationships with their students [6]. Moreover, research exploring teachers' emotional intelligence (EI) has revealed a strong connection between educators' ability to understand and manage emotions and students' academic achievement. Studies using the Daniel Goleman questionnaire [7], show that EI encompasses self-awareness, emotional regulation, self-motivation, empathy, and social skills—all critical for creating positive learning environments. Teachers with higher EI are better equipped to foster student engagement, support meaningful social interactions, and respond effectively to students' emotional and cognitive needs [8]. These findings underscore the importance of integrating EI development and empathy training into HE teacher academic programs, as such competencies contribute not only to improved student learning outcomes but also to a more supportive and motivating educational climate.

Moreover, the increasing shift to online education has raised the importance of virtual empathy, a key digital competence that can foster positive learning experiences in virtual learning environments. In the context of Massive Open Online Courses (MOOCs), virtual empathy becomes particularly relevant, as it supports the creation of challenge-based and peer-learning activities that not only transfer knowledge but also cultivate collaborative problem-solving, social engagement, and awareness of diverse perspectives. MOOCs that integrate these

empathic design principles can better address both the cognitive and emotional needs of learners, promoting more effective and inclusive online education while enhancing learners' capacity for innovation and sustainable thinking [9]. Recent interdisciplinary research further conceptualises empathy as a multi-layered process involving communication competence (e.g., emotion recognition and expression), emotion regulation, and higher-level cognitive mechanisms such as perspective-taking and theory of mind, all of which are essential for meaningful social interaction and engagement in both human and digital environments [10]. These findings further show that systems capable of expressing empathy have been shown to increase trust, engagement, and the quality of interaction, highlighting the importance of integrating empathic principles into the design of interactive and educational technologies.

Recent research also highlights that empathy plays a crucial role in enabling individuals to effectively integrate diverse perspectives, reducing misunderstandings and enhancing collaboration, which ultimately leads to more creative and original outcomes in team-based problem-solving contexts [11]. One other example, a study exploring the impact of online education on empathy shows that different factors, such as exposure to digital technology and gender, can influence the way empathy is expressed in an online educational environment [8]. This highlights the importance of virtual empathy as digital competence in online learning environments, where the ability to connect emotionally with others and understand their perspectives plays a crucial role in fostering positive learning experiences [12]. Thus, virtual empathy plays a key role in developing online learning materials that effectively address students' emotional and cognitive needs.

Understanding students' learning preferences is closely intertwined with the development of scientific empathy in STEAM education. Different cognitive and metacognitive preferences, such as visual, auditory, reading/writing, kinesthetic, reflective, and global approaches, influence how learners perceive, process, and emotionally engage with scientific content within designed learning materials [13]. Systematic literature reviews in science education have shown that each student's unique learning preference, combining cognitive, affective, and psychomotor factors, directly affects learning experiences, engagement, and performance [14]. By recognising and accommodating these diverse learning modalities, educators can design learning approaches that not only enhance comprehension but also foster empathetic understanding of complex socio-scientific and sustainability-related challenges. Furthermore, integrating learning-preference-based strategies and modern media, such as simulations, animations, and interactive content, can provide tailored support that encourages both cognitive and emotional engagement.

For instance, visual learners may develop deeper scientific empathy when sustainability concepts are represented through diagrams or concept maps [15], [16]. In contrast, auditory learners benefit from discussions and collaborative activities that encourage multiple perspectives. Kinesthetic and hands-on learners strengthen their empathetic reasoning through simulations [17], virtual reality (VR) experiments [18], and real-world problem-solving. Reflective and global learners integrate knowledge across disciplines, considering systemic implications and ethical dimensions, thereby enhancing their capacity for innovative and sustainable solutions. Recent research on immersive virtual reality further supports this by showing that VR-based perspective-taking can enhance empathic responses by allowing learners to embody others' experiences, while factors such as immersion, presence, and embodiment significantly influence the intensity of these effects [19]. Incorporating learning preferences into empathy-driven content design supports the creation of adaptive, inclusive, and emotionally engaging learning materials, promoting not only effective knowledge acquisition but also the development of responsible, forward-thinking scientific experts [20], [21].

Building on these findings, this study introduces an empathetic questionnaire designed to explore students' learning preferences, emotional responses, and engagement within an online educational context. Unlike the TEQ, which focuses on general empathy, the questionnaire in

this study is intended to capture the unique cognitive and emotional needs of students, providing insights into how these factors influence their learning preferences within the STEAM context. This study investigates how this information could inform the development of tailored e-learning materials that adapt to the diverse cultural, cognitive, and emotional profiles of students. By using an empathetic questionnaire, this study aims to explore how students tend to process and connect with e-learning content, supporting the design of educational experiences that are potentially more emotionally engaging and aligned with learning preferences. The questionnaire assesses not only cognitive learning preferences (e.g., visual, auditory, or hands-on) but also metacognitive strategies like reflective and structured learning, which may provide valuable guidance for creating content that resonates with students' needs and supports improved learning outcomes.

METHODS

To systematically explore the role of empathy and learning preferences in STEAM higher education, the study employed a structured methodological framework. The approach combined theoretical grounding with empirical data collection to capture both cognitive and emotional dimensions of student learning. Emphasis was placed on understanding how students engage with learning content, how their preferences shape interaction with educational materials, and how these factors vary across diverse cultural and institutional contexts in European higher education. The following sections detail the specific tools, instruments, and participant recruitment procedures used to gather and analyse the data.

The Role of Empathy in Science, Technology, Engineering, Arts and Mathematics Higher Education

Empathy is generally understood as the capacity to perceive, understand, and respond to the emotional and mental states of others. Although the term has its linguistic roots in ancient Greek, meaning “feeling into,” its scientific use emerged relatively late, first appearing in early twentieth-century psychology and aesthetics before evolving into a key concept for understanding social cognition and human interaction [1], [22]. At its core, empathy involves an affective response that is triggered by observing, imagining, or inferring another person's emotional state, alongside the awareness that this state originates in the other. Modern research commonly distinguishes empathy into emotional empathy and cognitive empathy, with the latter further divided into affective theory of mind (ToM) and cognitive theory of mind [1]. Emotional empathy refers to the automatic sharing of another person's feelings, while affective ToM involves consciously recognising and reasoning about others' emotions, and cognitive ToM relates to understanding others' thoughts, intentions, and beliefs. Together, these interrelated dimensions reflect the complex cognitive and emotional processes through which individuals make sense of others as thinking and feeling beings.

Empathy plays a significant and often underappreciated role in scientific learning, particularly in contexts that engage students both cognitively and emotionally. Research indicates that many effective science education interventions already involve empathising processes, even if this is not explicitly recognised [20], [23]. Emotional empathy, for instance, is activated through social interactions among students and between students and lecturers, fostering motivation and engagement in collaborative and practical learning activities. Cognitive empathy, including affective and cognitive ToM, enables learners to understand others' perspectives, intentions, and feelings, which is particularly relevant when addressing socio-scientific issues that are open-ended, controversial, and morally or ethically charged. Science topics related to health and the environment are especially effective for eliciting empathic engagement, as they connect scientific concepts to real-life human and ecological concerns [21], [24]. Simulation-Based Learning (SBL) provides a concrete example of how empathy can be integrated into science education. For instance, in SBL, students actively

participate in scenarios that simulate complex, real-world problems, using structured rubrics such as the empathetic patterns in interpersonal communication (EPIC) model to identify and analyse empathic patterns. These experiences enhance students' ability to recognise cognitive and emotional aspects of empathy, develop situational interest, and engage collaboratively in problem-solving, mirroring the processes observed in scientific practice [17]. Moreover, empathy and theory of mind are particularly crucial in medical and healthcare education, where students' ability to understand and respond to patients' emotions directly affects care quality. For instance, studies among dental students have shown that higher empathy levels, as measured by the Toronto Empathy Questionnaire and the Reading the Mind in the Eyes Test, are associated with better understanding of patients' needs and ethical decision-making [25]. Such research highlights that incorporating structured empathy training, communication skill development, and practical experiences with patients into curricula is vital for preparing students to provide patient-centred care. These findings underscore that, beyond cognitive learning, cultivating emotional and social skills through empathy is essential for students entering professional practice in dynamic, human-centred fields.

Furthermore, recent research demonstrates that HE institutional frameworks can also influence students' empathy and willingness to innovate [26]. Studies show that comprehensive evaluation systems that consider both the research process and output stimulate students' empathic engagement with their work and encourage innovative thinking. By integrating dynamic, process-oriented assessments rather than focusing solely on quantity or traditional metrics, universities can foster an environment where empathy drives the responsible and sustainable use of knowledge resources. This highlights the broader impact of empathy, extending beyond classroom learning to systemic academic and research practices, and underscores its critical role in cultivating innovative solutions for sustainability challenges. Incorporating empathy into STEAM higher education not only increases student motivation but also supports the development of prosocial relationships, ethical thinking, and innovative learning approaches among professors, students, and other staff at HEIs, which is necessary for addressing current and future environmental and social challenges.

Learning Preferences as a Basis for Flexible Learning Strategies

Understanding learning modalities is crucial for developing preference-aligned educational content and methodologies tailored to the diverse ways in which students absorb, process, and apply knowledge. Learning preferences refer to the individual differences in how students prefer to engage with content. There are different classifications of learning preferences, some of which are more widely used and recognised in pedagogical practice. Among the most well-known is Kolb's model of learning styles [27], which categorises learners as convergers, assimilators, divergers, and accommodators based on their preferences for experiencing, thinking, observing, and experimenting. Other common models include the VARK model (visual, auditory, reading-writing, kinesthetic) [28], Gardner's theory of multiple intelligences [29], and the Felder-Silverman model [30].

One research on STEAM education has shown that learning preferences have a significant impact on students' attitudes toward STEAM subjects [31]. The study revealed that students with converger and assimilator learning preferences demonstrated more positive attitudes toward STEAM learning, while diverger and accommodator students exhibited lower levels of motivation and interest. This highlights the importance of adapting teaching approaches to different learning preferences and incorporating collaborative and hands-on activities that can engage students, especially those who may not traditionally show a strong interest in STEAM subjects.

Despite the common belief in the effectiveness of learning preferences, there is some recent research questioning their impact on improving learning outcomes. A survey of UK HE teachers found that although many teachers still believe in the effectiveness of learning styles, the actual use of these classifications in teaching is relatively low [32]. This discrepancy between belief and practice suggests that, although learning styles are often cited as a useful tool for adapting

teaching, there is a lack of evidence to support their effectiveness. Consequently, instead of rigidly classifying learners by learning styles, it may be more beneficial to emphasise a flexible approach that incorporates a variety of teaching methods capable of addressing diverse learning needs. Therefore, it may be more useful in STEAM education to emphasise flexible teaching methods that include a variety of approaches that can appeal to a broader range of learners and stimulate a deeper interest in these subjects, whatever their learning style.

Building on this pedagogical perspective, the empathetic questionnaire focuses on cognitive learning preferences by examining how learners process and absorb information, rather than assigning them to rigid categories. This approach is aligned with the VARK model, which highlights sensory preferences such as visual, auditory, reading/writing, and hands-on learning. Each cognitive preference (Figure 1, left) represents distinct strengths in acquiring, organising, and retaining knowledge, providing a foundation for designing learning content that is flexible, inclusive, and responsive to diverse learning strategies. Complementing this, metacognitive learning preferences (Figure 1, right) capture how learners regulate their learning processes, including planning, reflection, and strategy adaptation. These preferences encompass structured, reflective, and holistic approaches to learning, which are particularly important when addressing complex and interdisciplinary topics such as sustainability and innovation. Table 1 synthesises both cognitive and metacognitive learning preferences, outlining their core characteristics and preferred learning strategies and serves as a practical reference for the development of adaptable and inclusive educational content in STEAM higher education.



Figure 1. Cognitive (left) and metacognitive (right) learning preferences considered within the IGNITE empathetic questionnaire

Understanding sustainability as a meta-context from a whole-system perspective is essential for enabling students to recognise the societal, environmental, and technological implications of their decisions. Such systemic understanding is closely linked to the development of scientific empathy, as it encourages learners to consider the consequences of actions for diverse stakeholders and to navigate complex dilemmas inherent to sustainable development and innovation, as highlighted in recent research on engineering education and curriculum renewal [33]. To support this process, learning approaches that integrate multiple cognitive and metacognitive preferences offer diverse and inclusive pathways for engaging with complex sustainability-related content. One particularly effective approach is the use of concept maps, which enable learners to visually structure and interconnect interdisciplinary knowledge, making abstract systems and relationships more tangible and accessible [15]. Concept maps accommodate a wide range of learning preferences: visual learners benefit from graphical representations, auditory learners from

collaborative discussions around the maps, reading/writing learners from annotating and elaborating concepts, and kinesthetic learners from actively constructing maps and simulating real-world problem-solving scenarios. At the metacognitive level, active learners engage through hands-on and collaborative tasks, reflective learners deepen understanding through analysis and synthesis, sequential learners follow logically structured pathways, and global learners grasp overarching system-level connections. In this way, concept maps not only enhance comprehension and critical thinking but also support the development of scientific empathy, innovation, and sustainable decision-making in higher education learning environments.

Table 1. Overview of cognitive and metacognitive learning preferences with main characteristics and recommended learning strategies

Learning preference	Key characteristics	Preferred learning strategies
Cognitive preferences	Visual learners (A)	Prefer images, diagrams, charts, graphical representations
	Auditory learners (B)	Understand concepts through listening and speaking, prefer verbal instructions
	Reading/writing learners (C)	Learn best through reading and writing, surpass in comprehension and expression
	Kinesthetic learners (D)	Prefer hands-on, practical learning, learn through doing
	Active learners (A)	Engage deeply with material through interaction and participation
Metacognitive preferences	Reflective learners (B)	Process information internally before acting, prefer self-reflection
	Sequential learners (C)	Learn in a structured, step-by-step manner, appreciate order
	Global learners (D)	Prefer to understand the overall concept first, connect ideas creatively

Empathetic Questionnaire

In this study, the primary methodological tool was an empathetic questionnaire developed to systematically capture students' cognitive and metacognitive learning preferences,

motivational factors, and emotional engagement in STEAM higher education. The questionnaire is designed to explore how learners experience different learning situations, perceive content emotionally, and how these factors influence engagement with educational materials. It focuses on the learning process rather than outcomes, providing insight into how emotional and cognitive dispositions shape approaches to learning, particularly in digital environments. To enhance transparency and reproducibility, the full questionnaire is provided in

Table 2, alongside a clear explanation of which items assess which constructs. Cognitive learning preferences part measures preferred methods of receiving and processing information, motivational factors, and emotional engagement. Metacognitive learning preferences section measures how learners organise, reflect, and structure their learning.

Table 2. Empathetic questionnaire items, response options, and corresponding learning constructs

Question	Response options	Concept measured
Cognitive learning preferences		
How do you prefer to receive information?	visual / auditory / written / hands-on	Cognitive learning preference (primary modality)
When learning something new, what helps you most?	diagrams, charts, or visual explanations / listening or discussion / reading or writing / learning by doing	Cognitive processing strategy, engagement preference
What motivates you to engage with content?	relevance to life or goals / personal stories / reading inspiring articles / hands-on experience	Motivation and engagement drivers
When do you feel most emotionally connected to the content?	visualisation / discussion / deep reading / practical application	Emotional engagement
When learning about sustainable innovations, which method helps you understand concepts best?	infographics, videos, diagrams / podcasts, discussions, presentations / reading articles or research papers / hands-on projects	Topic-specific cognitive preference (sustainability)
Which method is most effective for exploring entrepreneurial innovation?	visual aids / podcasts or panels / reading case studies, research report / collaborative workshops or innovation labs	Topic-specific cognitive preference (entrepreneurship)
Metacognitive learning preferences		
When learning new material, which approach helps you understand and remember best?	group discussions or hands-on activities / reflection / stepwise / broader context	Metacognitive learning strategies
How fast do you prefer content to be delivered?	quick / moderate / structured / overview-first	Pacing preference (metacognitive factor)
How do you prefer to use digital technology/social media (short videos) for learning?	interactive quizzes / slower pace with pause and notes / break down concepts and stepwise / overview-then-detail	Interaction with digital tools, preference for learning format

The use of the empathetic questionnaire supports a more nuanced understanding of how students relate to different forms of learning content, allowing educational materials, teaching methods, and learning environments to be adapted in a targeted and evidence-informed manner. Within the Erasmus+ IGNITE project, these findings will inform the design of personalised and flexible learning pathways, enhancing both the alignment with students' learning preferences and inclusiveness of learning experiences. In addition, the questionnaire encourages structured self-reflection, enabling students to become more aware of how their emotional and cognitive dispositions influence their learning, thereby fostering greater self-regulation and adaptability.

In the context of e-learning, the questionnaire was applied to identify patterns of emotional engagement and cognitive preferences that influence students' interaction with digital learning materials. The results provide a basis for the development of adaptive nanolearning modules, tailored in terms of pacing, interactivity, and content structure, which are critical for sustaining motivation and engagement in online learning environments. Importantly, the questionnaire also serves as a mechanism for monitoring the development of students' digital and scientific empathy competencies over time. When integrated into the IGNITE competence assessment application, the results will be used by an e-assistant to recommend supplementary educational activities, such as workshops, lectures, or webinars, aligned with individual learning preferences. In this way, the empathetic questionnaire functions not only as a diagnostic tool but also as a dynamic component of an adaptive, learner-centred digital education ecosystem, suitable for culturally and educationally diverse student populations. In a similar vein, research by Kanchon *et al.* has shown that identifying learners' preferred learning preferences using artificial intelligence (AI) techniques, such as analysing web-tracking logs and categorising responses, can significantly enhance learning content adaptation [34]. By using AI-based learning preference detection and content modification, the learning experience can be personalised to foster a more preference-responsive and engaging educational environment. This approach allows learning to be tailored to the specific needs of students, increasing the preference-alignment and engagement of the learning process in a digital environment.

The empathetic questionnaire used in this study was specifically designed to explore students' cognitive and metacognitive learning preferences in relation to sustainable and entrepreneurial innovation. It consisted of nine multiple-choice questions, divided into two main sections. The first section focused on cognitive learning preferences, examining how students prefer to receive and engage with information—visually, auditorily, through written content, or via hands-on experience. This part also addressed emotional engagement and motivation in learning contexts, particularly regarding sustainable and entrepreneurial topics. The second section assessed metacognitive learning preferences, looking into how students structure their learning processes, their preferred pace of content delivery, and their use of digital technology and social media for learning. The responses provided insights into students' reflective habits, their preference for sequential or contextualised content, and their interaction with online learning materials such as short videos and interactive quizzes. Data were collected through a combination of methods; invitations were sent to students via institutional mailing lists of participating HEIs, and the questionnaire was also shared on social media platforms to increase reach and participation.

Survey Participants

Participants were recruited using a convenience sampling approach within partner higher education institutions participating in the Erasmus+ IGNITE project. The inclusion criterion required participants to be currently enrolled in a STEAM-related higher education programme at the bachelor's, master's, or doctoral level. Participation was voluntary and anonymous. The questionnaire did not collect personal demographic data such as gender, age, or study level. No information on year of study, prior experience with e-learning, or prior exposure to sustainability and entrepreneurship topics was collected. The only background variable recorded was the higher

education institution in which the participant was currently enrolled. This decision was made to ensure anonymity and to encourage participation across institutions. Given the exploratory and descriptive nature of this study, and the non-probabilistic sampling strategy, the analysis focuses on descriptive statistics rather than inferential statistical testing. Therefore, comparisons between institutions are reported cautiously, and no causal claims are made.

A total of 108 participants took part in this study, with their distribution based on their current higher education institution (HEI) as shown in the chart below. The participants were from different HEIs across various European countries, providing a broader insight into the learning preferences of students from diverse cultural and educational contexts. The distribution of participants is presented in Figure 2. The highest proportion of participants came from the University of Lorraine (27.8%), followed by students from the Norwegian University of Science and Technology (25%). A slightly smaller percentage of participants was from Polytechnic University of Catalonia (13.9%), the University of Gent (14.8%), and Jozef Stefan International Postgraduate School (18.5%). This diverse distribution of participants supports descriptive comparisons of learning preferences across institutions while acknowledging that the lack of detailed demographic and prior experience data limits broader generalisation.

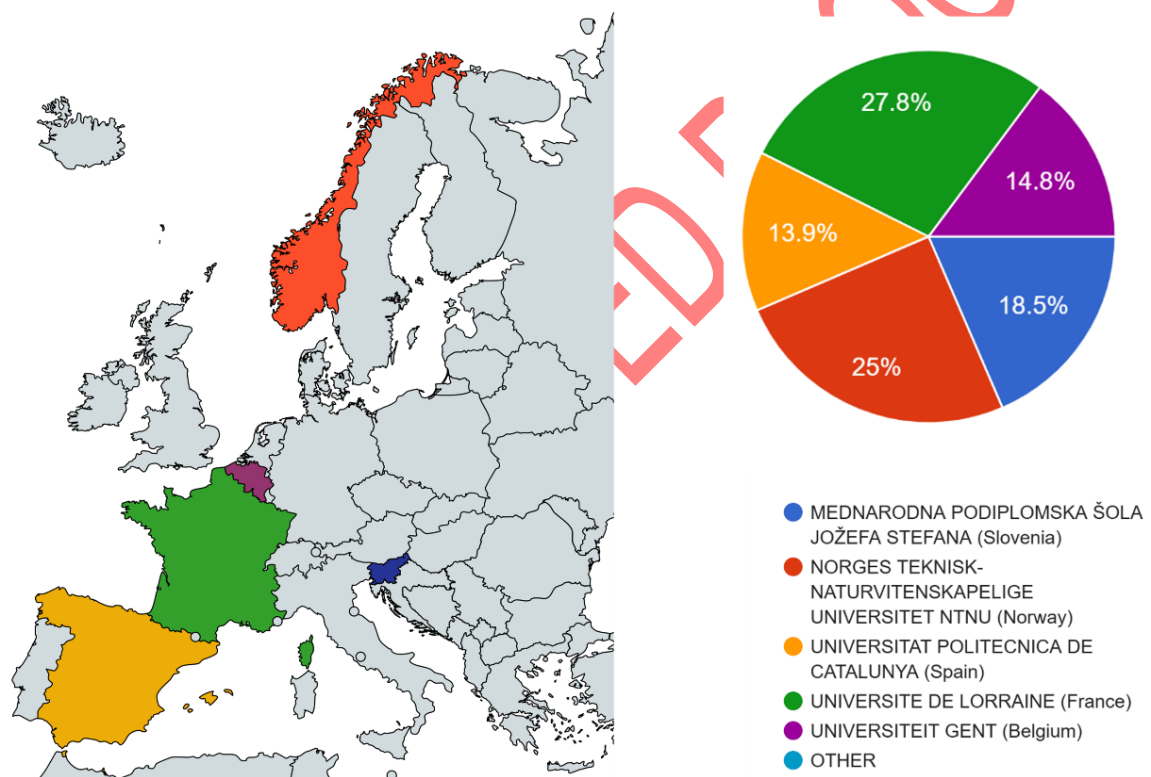


Figure 2. Distribution of survey participants by higher education institution

RESULTS

The following section presents the findings of the study, providing a comprehensive overview of students' cognitive and metacognitive learning preferences, motivational factors, and emotional engagement patterns in STEAM higher education. Data are reported across diverse European institutions to illustrate variations in learning approaches, engagement strategies, and preferred digital media usage. The results are organised to first address cognitive learning preferences, followed by metacognitive preferences, and concluding with cross-country comparisons and contextual insights.

Cognitive Learning Preferences among Students

The chart presented in Figure 3 depicts the distribution of preferred information delivery methods among the 108 survey participants. These findings can inform the design of educational materials and instructional strategies aligned with learners' predominant cognitive preferences. Visual learning appeared as the most frequently preferred modality, reported by 47.2% of participants, indicating that nearly half of the respondents may favour the acquisition of information through graphical representations such as images, diagrams, and charts. Written learning was identified as the second most prevalent preference, selected by 26.9% of participants, suggesting a substantial inclination towards text-based materials and written explanations. Hands-on learning, preferred by 13.9% of respondents, reflects the importance of experiential and practice-oriented learning approaches, particularly in applied learning contexts. Auditory learning was the least preferred modality, chosen by 12% of participants, indicating that learning primarily through listening may play a comparatively smaller role among the surveyed population.

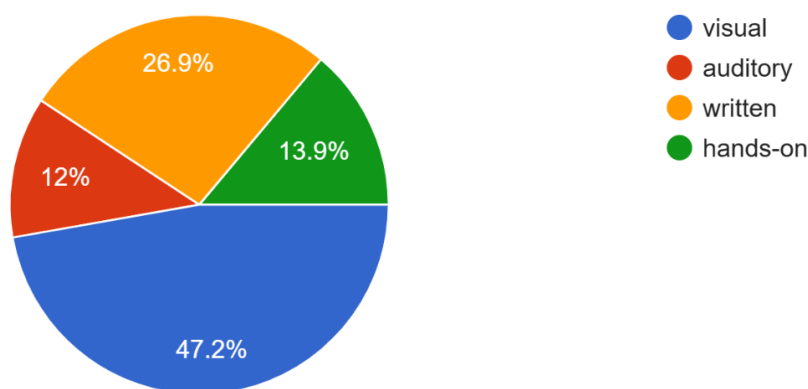


Figure 3. Preferred methods of receiving information among students

Figure 4 illustrates the key motivational factors influencing content engagement among the 108 survey participants. The most prominent motivator, reported by 45.4% of respondents, was the perceived relevance of the content to their personal lives or future professional goals, suggesting the potential importance of practical applicability and goal-oriented learning in sustaining learner engagement. The second most influential motivational factor, selected by 27.8% of participants, was the opportunity to gain hands-on experience or actively experiment with the content, reflecting the possible role of experiential learning and active participation in fostering deeper engagement and motivation. In contrast, more narrative-based motivational elements were less influential: only 13.0% of participants identified hearing personal stories or testimonials related to the content as motivating, while 13.9% reported motivation through reading inspiring articles and case studies. These findings suggest that, although storytelling and reflective materials may support engagement for a subset of learners, they are generally less preferred motivators compared to experiential and relevance-driven approaches in STEAM education.

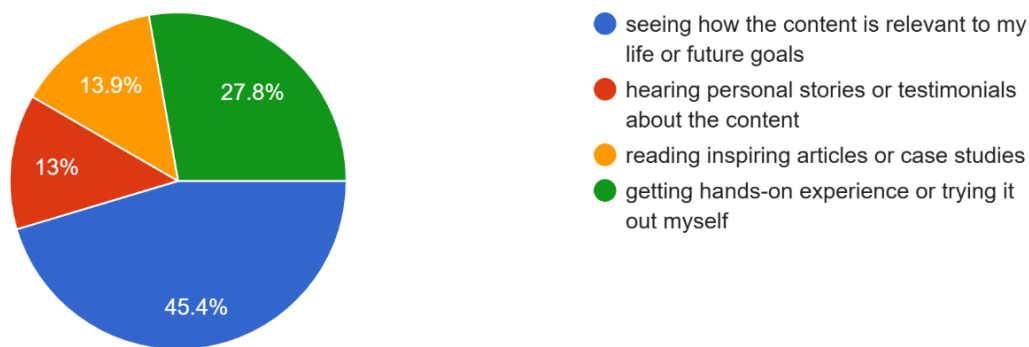


Figure 4. Key motivators for content engagement among survey participants

Figure 5 presents participants’ responses regarding the conditions under which they experience the strongest emotional connection to learning content. The largest proportion of respondents (38.9%) reported the highest level of emotional engagement when they were able to interact with the content through practical application, suggesting the central role of experiential and hands-on learning in fostering affective involvement. Visualisation appeared as the second most influential factor, with 25.0% of participants indicating that visual representations may enhance their emotional connection, reflecting previous findings on the affective impact of visually mediated learning. Social interaction also seems to play a notable role, as 24.1% of respondents reported increased emotional connection when discussing content with others, suggesting the importance of collaborative and dialogic learning processes. These patterns may reflect key dimensions of scientific empathy, as learners appear to engage more deeply when they can relate scientific content to real-world actions, shared perspectives, and meaningful contexts.

In contrast, only 12.0% of participants indicated that deep reading of textual materials elicited the strongest emotional connection, suggesting that text-based approaches alone may be insufficient to stimulate affective engagement for most learners. These findings suggest that traditional instructional models, which predominantly rely on reading and writing, may not adequately address the emotional dimension of learning, particularly in digital and self-directed learning environments. Conversely, pedagogical approaches that integrate experiential activities, visual elements, and opportunities for social interaction may be more likely to promote both emotional and cognitive engagement. This interpretation is consistent with prior research indicating that creativity-oriented learning preferences—such as active idea generation and immersive engagement—can enhance learning motivation and engagement in STEAM education [35]. Accordingly, the design of preference-aligned online learning environments should consider prioritising practical, visual, and socially interactive components to strengthen emotional connection, support scientific empathy, and enable deeper learning outcomes.

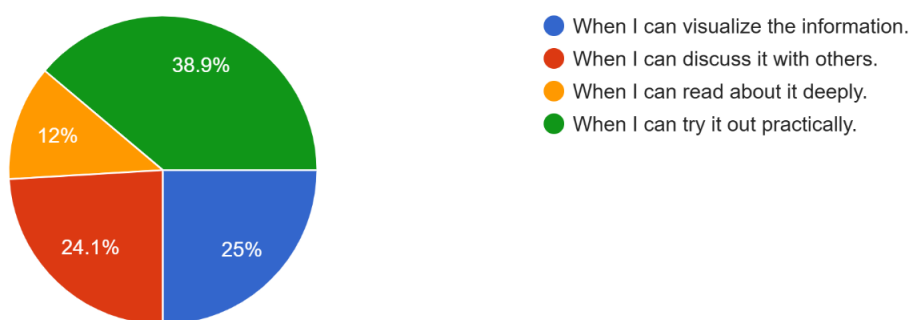


Figure 5. Factors that foster emotional connection to content

Figure 6 presents students' preferred methods for understanding concepts related to sustainable and entrepreneurial innovation. In the context of sustainable innovation, the most frequently selected approach (37.0%) involved visual representations, suggesting the potential importance of visualisation in facilitating comprehension of complex sustainability-related systems and processes. Experiential learning through hands-on projects or experiments was identified as the second most preferred method (30.6%), reflecting the value of active engagement when exploring sustainable solutions. A smaller yet substantial proportion of participants (20.4%) preferred learning through reading articles, research papers, or case studies, indicating reliance on in-depth textual analysis. Auditory approaches, including podcasts, discussions, or presentations, were least favoured in this context (12.0%), suggesting limited preference of listening-based learning for sustainability-related topics among many respondents.

In contrast, preferences related to entrepreneurial innovation appeared to exhibit a different pattern. The most preferred method reported by participants (32.4%) was listening to expert panels or podcasts, indicating the relevance of auditory learning and exposure to real-world experiences in understanding entrepreneurial approaches to social and economic challenges. Participating in collaborative workshops or innovation labs ranked second (26.9%), suggesting the importance of interactive, practice-oriented learning environments that support teamwork, networking, and problem-solving. Visual tools, such as infographics or concept maps, were preferred by 25.0% of respondents, reflecting their continued relevance for structuring and understanding entrepreneurial frameworks. Reading case studies, research reports, or academic articles was identified as the least preferred method (15.7%), indicating that purely text-based learning may play a more limited role in this domain.

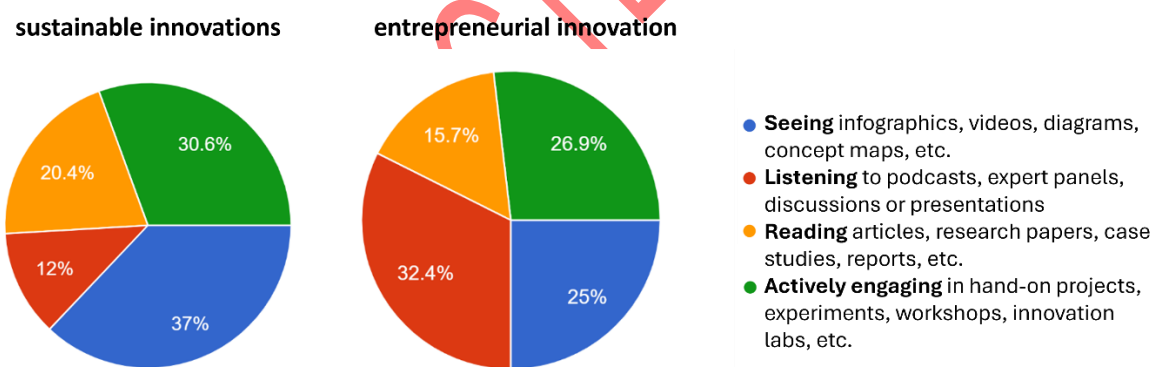


Figure 6. Preferred learning methods for understanding sustainable innovations and exploring entrepreneurial innovation

The contrasting patterns observed between sustainable and entrepreneurial innovation can be attributed to the differing epistemic and contextual demands of these fields. Sustainable innovation often involves the analysis of complex environmental, technical, and systemic interactions, which benefit from visualisation and experiential learning strategies that support systems thinking. Entrepreneurial innovation, by contrast, is more closely linked to real-world practice, market dynamics, and socio-economic contexts, where learning from practitioners' experiences and peer interaction becomes particularly valuable. Listening to experts provides access to tacit knowledge and applied insights, while workshops and collaborative activities align with the entrepreneurial emphasis on iterative problem-solving and innovation in dynamic settings.

Overall, these findings indicate that the preference-aligned design of educational content in innovation-oriented higher education should adopt differentiated pedagogical strategies. Visual and experiential approaches appear particularly well suited to sustainability education, whereas entrepreneurial education benefits from a stronger integration of auditory, interactive, and experience-based learning methods. A balanced combination of visual, practical, and dialogic approaches is therefore essential for supporting diverse learning preferences and fostering meaningful engagement with both sustainable and entrepreneurial innovation.

Metacognitive Learning Preferences among Students

Figure 7 presents participants' preferences for approaches that help them understand and remember new material, reflecting different metacognitive learning preferences. The largest proportion of students (32.4%) prefers breaking down complicated topics into smaller, simpler steps, indicating that step-by-step learning is the most preferred method for many learners. The second most preferred approach, chosen by 31.5%, involves taking time to reflect on the material, highlighting the importance of self-reflection and processing in learning. In addition to self-reflection, self-assessment is crucial for effective learning. This can be achieved through short tests and tracking the development of competencies before and after a lecture or workshop. Such methods enable learners to evaluate their progress, identify gaps in understanding, and reinforce their learning outcomes, making the process more structured and impactful. Engaging in group discussions or hands-on activities was preferred by 21.3%, showing that some learners benefit from active application and collaboration. Lastly, 14.8% of participants favour understanding how new concepts fit into a larger context, suggesting that fewer learners prioritise a broader conceptual framework as their primary strategy.

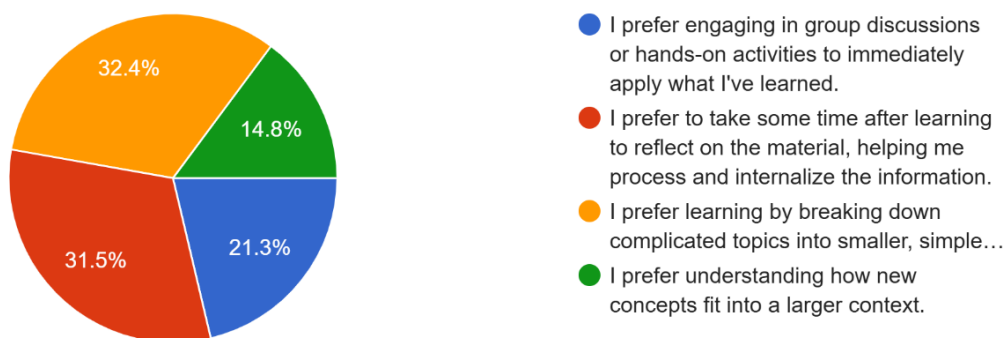


Figure 7. Preferred approaches for understanding and retaining new material

These findings emphasise the diversity in metacognitive learning preferences and the need to incorporate various approaches in educational settings to accommodate different learner preferences. The lower preference for "understanding how new concepts fit into a larger context" could stem from the fact that this approach requires broader knowledge, general awareness, and a deeper background of understanding, which learners develop over time through education and experience. Without a solid foundation of interdisciplinary knowledge and the ability to connect concepts across different domains, it can be challenging for learners to prioritise this strategy. This highlights the importance of fostering critical thinking, interdisciplinary learning, and broader contextual awareness throughout education to support this metacognitive approach.

Figure 8 highlights the preferences of respondents on how they like to use digital technology and social media, such as short videos, for learning. Most respondents (34.3%) prefer videos that break down concepts into clear, sequential steps, making the content easier to follow and understand. A significant portion (26.9%) enjoys videos that provide a quick overview first, followed by detailed explanations, which helps them grasp the bigger picture and connect new information to existing knowledge. Another 25.9% prefer videos with

interactive quizzes or questions throughout, keeping them engaged and facilitating real-time application of the material. Lastly, 13% prefer watching videos at a slower pace, allowing them to pause, reflect, and take notes as they learn. This distribution indicates that learners value structured, clear, and interactive content delivery when using digital media for education.



Figure 8. Preferred use of digital media and social videos for learning

Recent research on short educational movies demonstrates that these tools can be particularly effective in conveying complex environmental problems and promoting sustainable practices [36]. The cinematics and psychophysiological analyses show that careful planning of frame length, colour distribution, and narrative structure can significantly enhance viewer engagement and comprehension. For example, transition points in the videos, identified through Red-Green-Blue colour statistics, align with plot climaxes and emotional peaks, guiding attention, evoking specific feelings, and reinforcing key messages about environmental protection. Colours like red emphasise tension and urgency, blue fosters trust and reflection, and green restores balance and promotes renewal. These findings highlight that, when designed thoughtfully, short videos are not only visually appealing but also powerful pedagogical tools that structure information, maintain attention, and stimulate cognitive and emotional engagement in learners, making them highly suitable for sustainability education.

Differences in Students' Learning Strategies between Participating Countries

Understanding the differences in learning preferences across countries is crucial when designing educational content for platforms like YouTube, Facebook, Instagram or TikTok. These platforms are increasingly used for learning, especially among younger generations, and their global reach means that content must resonate with diverse audiences. Cultural and educational contexts shape how students engage with learning materials. Adapting content to these preferences ensures greater engagement, and accessibility of learning. For instance, while some cultures prioritise structured, step-by-step explanations, others may value hands-on learning or interactive elements. Moreover, differences in national skill structures and the path-dependent development of capabilities can further influence learners' engagement and the types of skills they are likely to acquire. Studies show that European countries exhibit substantial variation in skill portfolios, with northern and western nations tending toward socio-cognitive skills, whereas southern and eastern countries demonstrate comparative advantages in sensory-physical skills, and strong path dependence limits convergence across regions [37]. Additionally, students and learners from countries outside the EU often face additional challenges related to differences in educational systems, recognition of qualifications, and language barriers, which can influence their learning preferences, engagement, and ability to integrate effectively into local educational and professional contexts [38]. Addressing these factors through tailored content and support mechanisms is essential for ensuring equitable learning opportunities and skill development for third-country nationals. This implies that learners from different countries may approach, process, and prioritise content differently, reflecting not only cultural and educational traditions but also broader structural and economic

conditions that shape their skills and competencies. By tailoring educational strategies to both learning preferences and these contextual skill patterns, educators and content creators can create resources that foster deeper learning, enhance skill development, and promote equitable access to knowledge across diverse global audiences.

The data presented in Figure 9 depict the distribution of preferred learning preferences—auditory, hands-on, visual, and written—among students from five countries: Belgium, France, Spain, Norway, and Slovenia. Each bar represents the relative proportion of students adopting a particular learning preference, with the numerical values in each segment indicating the number of respondents selecting that option. Visual learning emerges as the predominant preference across the sample, with the highest prevalence observed in Norway, France, and Slovenia. In contrast, written learning is notably preferred in Belgium and Spain, whereas it is less prominent in Slovenia. Hands-on learning is consistently reported by a smaller fraction of students across all countries, highlighting a generally lower preference for experiential approaches in these contexts. Auditory learning exhibits the lowest prevalence overall, with minimal representation and no respondents selecting this preference in Norway, although a slight increase is observed in Spain, suggesting potential influences of cultural or contextual factors. The observed patterns underscore a strong inclination toward learning methods that involve visual observation and structured textual information, while the cross-country variability reflects underlying cultural, pedagogical, or systemic differences in educational practices that may shape students’ learning preferences. These findings are consistent with prior research on European skill structures, which shows that northern and western countries—such as Norway, Belgium, and France—tend to emphasise socio-cognitive skills, reflected in these results by the predominance of visual and written learning preferences. Conversely, in Spain, where sensory-physical skills are more prominent, students demonstrate relatively higher preferences for auditory and hands-on learning, aligning with the regional differences in skill specialisation identified in previous studies.

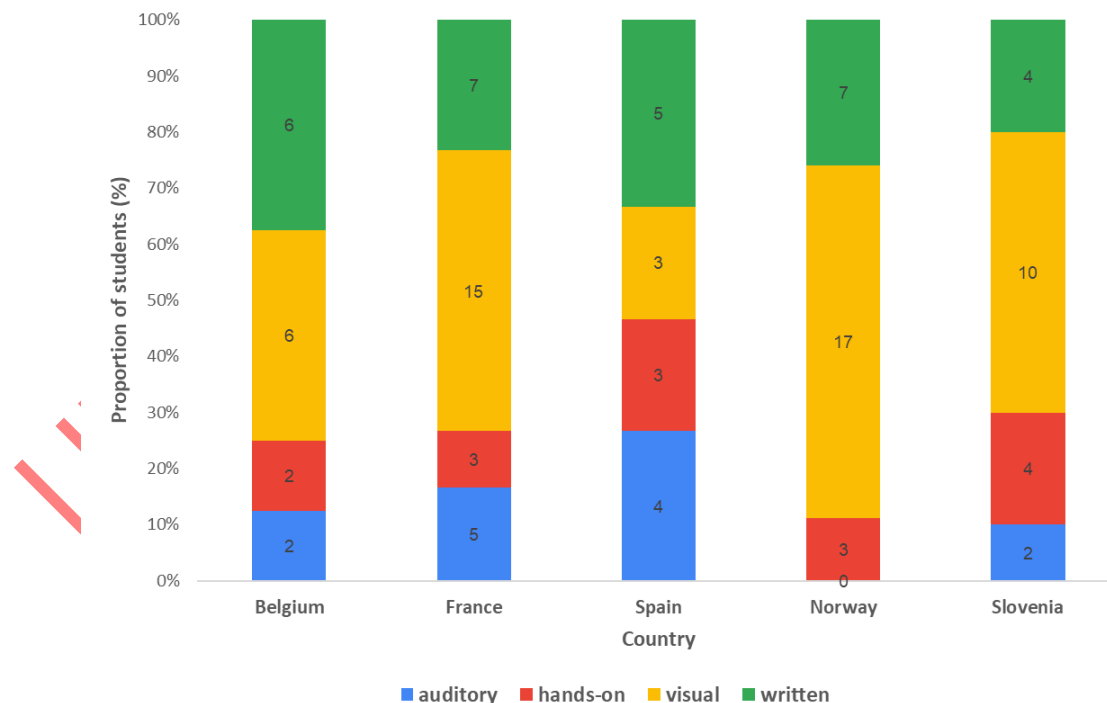


Figure 9. Distribution of learning preferences among students by participating country

The next graph in Figure 10 shows the proportion of students across all five countries based on their preferred methods of emotional connection to learning content. Students in Norway and Belgium feel the strongest emotional connection when they can visualise the information,

indicating a preference for imagery and visual aids in learning. France, Spain and Slovenia show the highest percentages of students who emotionally connect when they can try out the material practically. This suggests a preference for experiential and hands-on learning in these countries. A notable proportion of students in Norway and France connect emotionally through discussions, highlighting the importance of collaborative and social learning experiences. Very few students prefer emotionally connecting through deep reading, with the highest percentage in Belgium, and almost negligible in Spain and Norway. Practical application and visualisation are the two most preferred ways for students to feel emotionally connected to learning content across countries.

These preferences suggest the importance of engaging, hands-on tasks and visually appealing materials. Discussion-based learning plays a significant role, especially in Norway and France, where students value group interactions as a means of emotional connection. Deep reading is consistently low, indicating that written content alone is less preferred in fostering an emotional bond with learning material. To emotionally engage students across diverse cultural contexts, educational resources should emphasise hands-on activities, visual aids, and opportunities for discussion and collaboration, while using deep reading sparingly as a supplementary tool. Moreover, these patterns of emotional connection and preferred learning preferences align with broader trends in the distribution of skills across European countries [37]. Northern and western nations, such as Norway, Belgium, and France, are generally characterised by stronger socio-cognitive skills, corresponding in this study to a predominance of visual and written learning as well as emotional engagement through visualisation and discussion. Conversely, Spain, reflecting a relative emphasis on sensory-physical skills, shows higher preferences for hands-on and auditory learning, as well as emotional connection through practical activities. This correspondence suggests that students' emotional engagement and cognitive processing of learning content are influenced by underlying national skill profiles, highlighting the interplay between educational culture, skill specialisation, and the development of scientific empathy through contextually appropriate learning strategies.

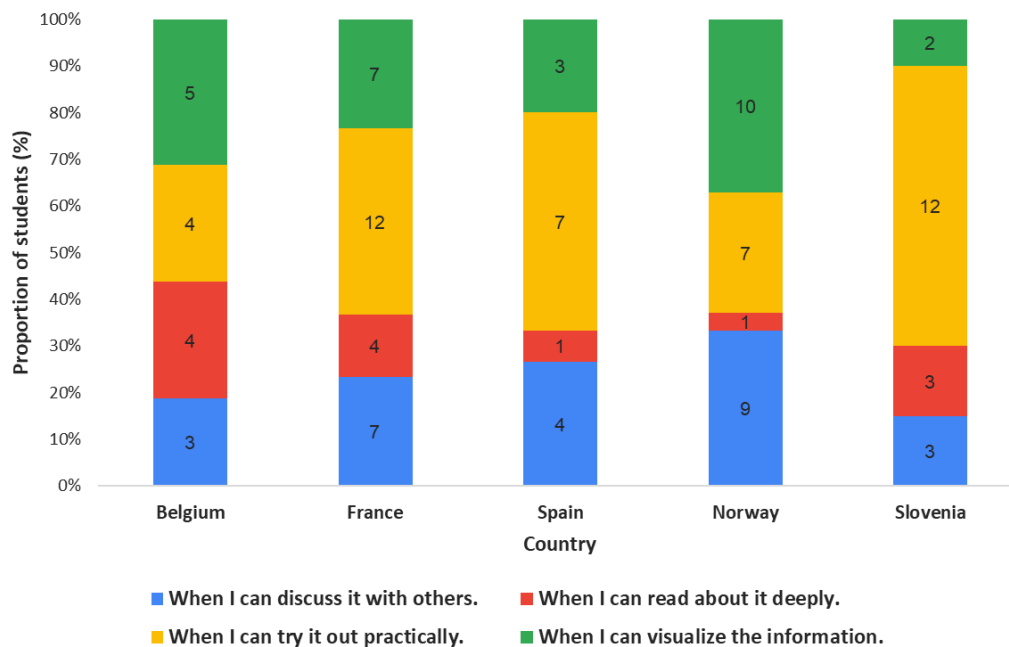


Figure 10. Emotional connection to learning content by preferred method and country

The following graph in Figure 11 shows the preferred learning methods for understanding sustainable innovations among students from different countries. The numbers in the columns represent the actual count of student responses for each category in each country. For Belgian students, the preference for hands-on projects (blue, 5) and visual aids (green, 5) is evenly

distributed. Fewer students chose reading articles (yellow, 4) or listening to audio-based content (red, 2). In France, visual aids (green, 10) are the most preferred, followed by reading articles (yellow, 8). Hands-on projects (blue, 9) are also popular, while listening to audio content is less favored (red, 3). In Spain, hands-on methods (blue, 5) and visual aids (green, 6) are almost equally preferred. Reading articles (yellow, 3) is less popular, with podcasts and discussions (red, 1) receiving minimal interest. Norwegian students strongly prefer visual aids (green, 13), significantly more than any other method. Hands-on projects (blue, 7) and audio-based content (red, 5) are moderately chosen, while reading articles is the least selected (yellow, 2). In Slovenia visual aids (green, 6) and hands-on projects (blue, 7) are almost equally significant. Articles (yellow, 5) are moderately chosen, and audio content (red, 2) is less favored.

Visual aids (green) are consistently among the top preferences across all countries, particularly in Norway, Spain and France. Hands-on projects (blue) are highly favoured, especially in France, Spain and Slovenia, indicating the importance of practical engagement in learning about sustainable innovations. Listening to podcasts and discussions (red) is the least chosen method across all countries, suggesting this mode of learning is less preferred for students in this context. Reading articles and case studies (yellow) is moderately popular but generally ranks below visual and hands-on methods. These patterns align with recent findings in sustainability education, where visual and hands-on methods support systemic understanding of complex socio-environmental issues and foster the development of scientific empathy, enabling students to consider the consequences of actions for diverse stakeholders [33]. Incorporating interactive visuals and practical, hands-on experiences provides diverse pathways for engaging different cognitive and metacognitive learning preferences, enhancing comprehension, critical thinking, and empathetic reasoning in sustainability contexts [15]. Thus, the observed preferences suggest that educational content designed for international audiences should combine visual, experiential, and collaborative approaches to preference-aligned support both cognitive understanding and emotional engagement with sustainability challenges.

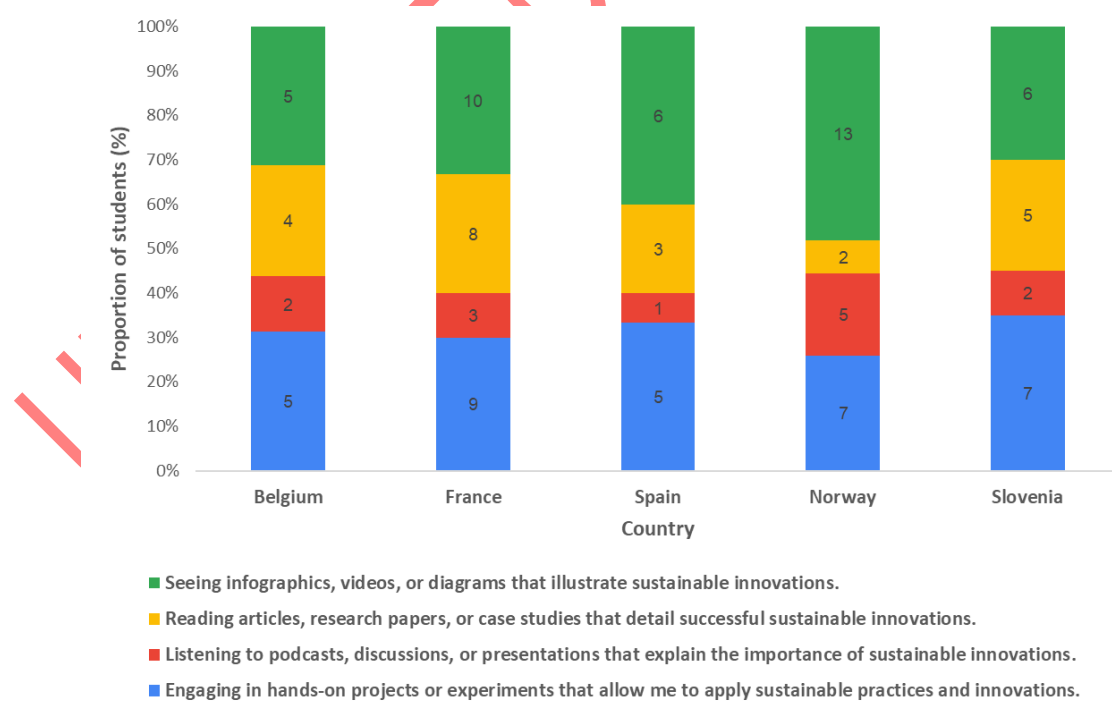


Figure 11. Preferred learning methods for understanding sustainable innovations among students by country

The graph in Figure 12 presents the preferred learning methods for exploring entrepreneurial innovation among students from five countries. The numbers within the columns indicate the actual count of student responses for each category in each country. Belgian students value visual methods and listening to expert discussions in the context of entrepreneurial innovation. Case studies (4 responses) are slightly less popular, while workshops (2 responses) are the least favoured. The most preferred method in France is podcast (10 responses). Both visual aids and case studies are equally popular (7 responses each), while workshops (3 responses) are the least favoured. Spanish students prefer practical and visual methods, while reading case studies does not appeal to them at all. Workshops (6 responses) and visual aids (6 responses) are equally favoured, while podcasts (3 responses) are moderately preferred. Norwegian students have a strong preference for hands-on and interactive learning, with less interest in traditional reading materials. Most students favour podcasts (12 responses), followed by workshops (7 responses). Visual aids (6 responses) are moderately preferred, while case studies (2 responses) are the least favoured. Slovenian students have a balanced preference for most methods, with workshops slightly leading. However, visual aids are less appealing.

Workshops (red) are popular learning method overall, particularly in Spain and Norway, highlighting the importance of interactive, hands-on approaches. Visual aids (green) are favoured in Belgium and Spain but are less popular in Slovenia. Podcasts (blue) are notably popular in France and Norway, but are less preferred in Spain. Case studies (yellow) are the least popular overall, except in Slovenia, where they are moderately appreciated. The graph reveals that students generally prefer interactive and practical learning methods, such as workshops, across most countries. Traditional approaches like reading case studies or journal articles are less attractive, particularly in Spain and Norway, suggesting the need for more engaging or innovative approaches to appeal to students. The data also reflects regional preferences, with visual and auditory methods (e.g., podcasts) varying in popularity across countries. Educational programs aimed at fostering entrepreneurial innovation should focus on interactive workshops and visual tools to actively engage students. While podcasts have potential, traditional reading materials might need to be supplemented with more engaging formats to appeal to students across all countries.

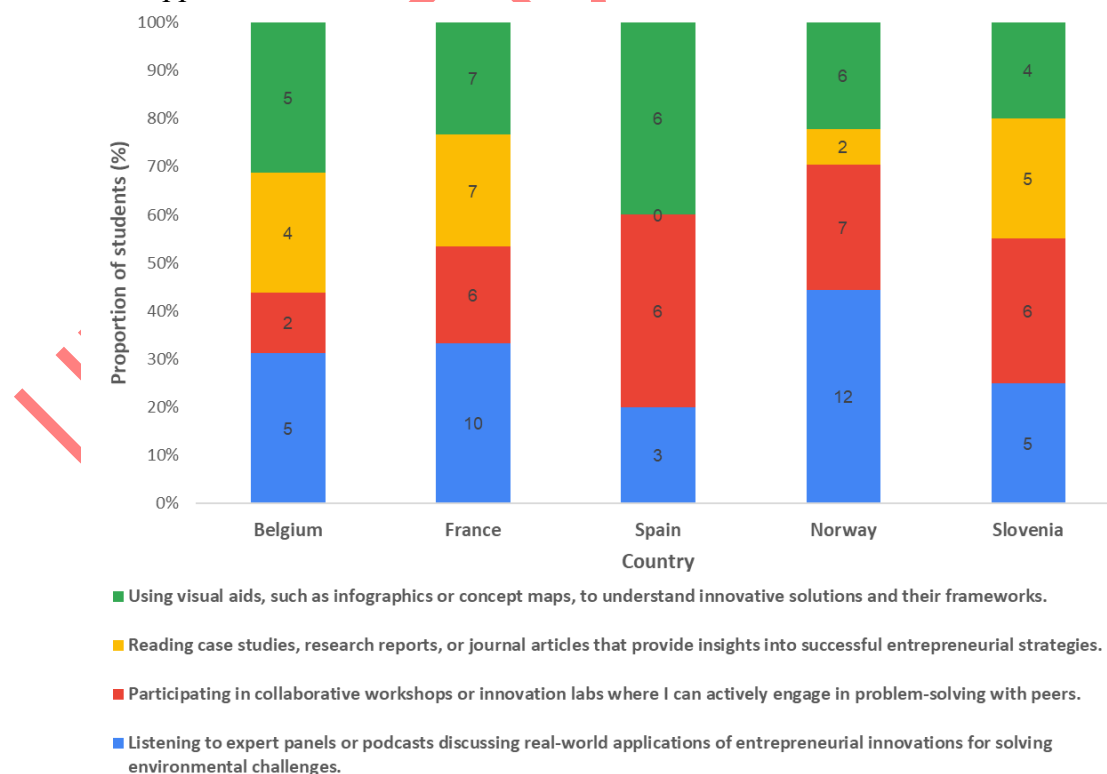


Figure 12. Preferred learning methods for exploring entrepreneurial innovation among students by country

Figure 13 illustrates the preferences of students from participating countries regarding the use of digital media and videos for learning. The vertical bars represent the number of students in each country who prefer specific preferences of video-based learning, with different colours indicating different approaches. Green preference (slower pace with time to pause and reflect) is consistent but not highly popular across countries, showing similar numbers. Videos incorporating interactive quizzes or questions (yellow) are most preferred by students in France (9). Norway, Spain and Slovenia show moderate interest. Red approach (clear, sequential steps) is a leading choice for students in France (10), Norway (10), and Slovenia (9). Spain (3) and Belgium (5) exhibit a slightly lower preference, though it is still significant. Videos that provide an overview first and then go into detail (blue) are particularly preferred in Norway (9) and France (9). Spain (3), Slovenia (4), and Belgium (4) show less interest in this approach.

The data highlights that videos breaking down concepts into clear, sequential steps (red) are the most favoured approach across several countries, particularly in Spain, Norway, and Slovenia. Interactive videos with quizzes (yellow) and videos offering a quick overview followed by details (blue) are also quite popular in most regions, reflecting an emphasis on engagement and structured content delivery. On the other hand, videos presented at a slower pace (green) have consistently lower appeal across all surveyed countries except Spain. This indicates a preference for dynamic, interactive, and well-structured video content for learning purposes.

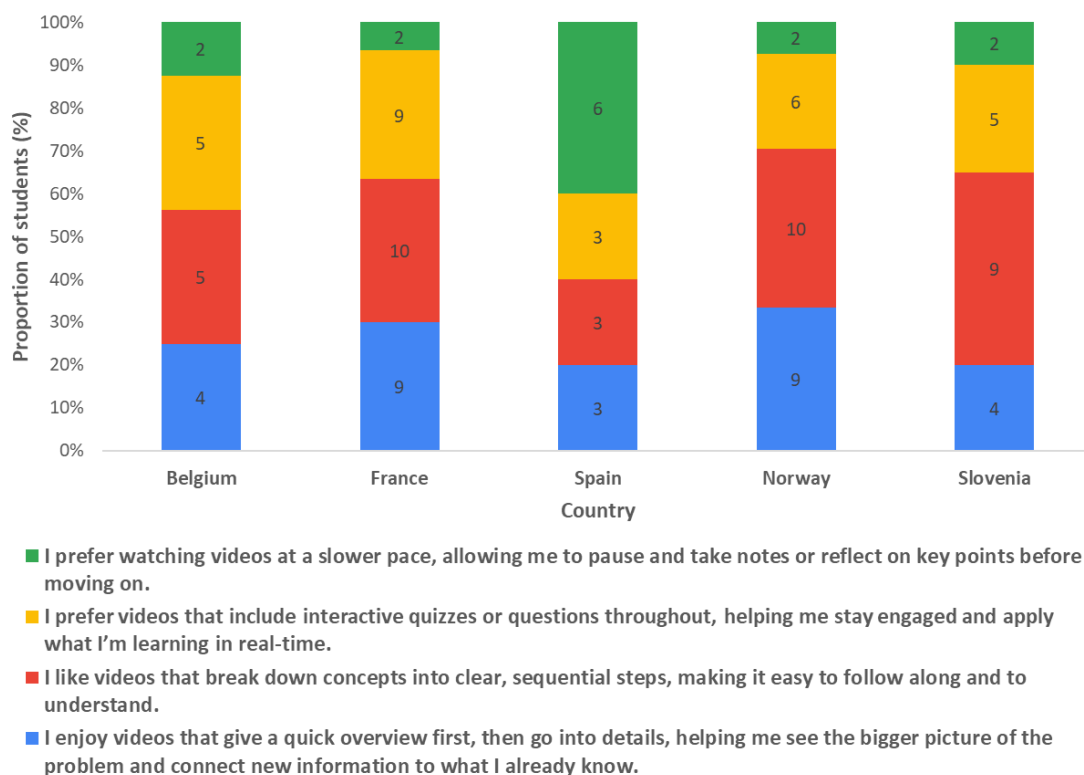


Figure 13. Preferred use of digital media and social videos for learning among students from different countries

DISCUSSION

In today's rapidly evolving educational landscape, it is essential to create learning environments that are responsive to the diverse needs of students. Understanding how students

learn, both cognitively and emotionally, may enhance the student-alignment of educational content and potentially foster greater engagement. Scientific empathy, which involves understanding both the cognitive and affective perspectives of learners, can play a vital role in fostering deeper connections between students, lecturers, and the learning material. By using an empathetic questionnaire, this study aims to identify students' learning preferences and emotional responses, providing insights for designing content that supports both cognitive processing and affective engagement. The findings suggest the importance of empathy in shaping educational experiences, particularly in e-learning environments, where virtual empathy may enhance connection and engagement.

Dominant Cognitive and Metacognitive Learning Preferences

The results of this study suggest that visual learning is among the dominant cognitive learning preference among the participants, with 47.2% preferring methods such as diagrams, charts, and infographics to process information. Additionally, 33.3% of students indicated diagrams and charts as the most helpful tools for learning new concepts. These findings suggest the value of clarity, organisation, and the rapid comprehension of complex ideas through visual representations. Visual learning may support cognitive processing by reducing cognitive load, enhancing retention, and facilitating the understanding of abstract or complex topics.

Sequential learning appeared as the most prevalent metacognitive learning preference, with 32.4% of participants favouring the breakdown of complex topics into smaller, structured steps. Similarly, 34.3% preferred video materials that present information in clear, sequential stages. This may indicate a preference for structured and logical approaches to understanding and retaining new material. Sequential learning can provide learners with a systematic framework to progress incrementally, ensuring clarity and reducing cognitive strain when processing complex information.

The study also suggests that learning preferences may be influenced by the subject matter. For sustainable innovation, students tended to prefer visual and practical methods, which could support the comprehension of environmental systems and interrelated processes. In contrast, entrepreneurial innovation appeared to benefit more from auditory and experiential approaches, indicating the importance of real-world practice, market dynamics, and peer interaction. These findings suggest that pedagogy might be optimised by aligning learning strategies with the characteristics and demands of the subject while combining structured, visual, and experiential elements to potentially enhance both cognitive and affective engagement.

Despite the widespread popularity of visual and sequential learning preferences among participants, extensive literature questions the effectiveness of rigidly assigning students to specific learning preferences. Research indicates that labelling learners as visual, auditory, or hands-on primarily affects perceptions of intelligence and ability rather than actual learning outcomes, highlighting the risk of neuromyths [39]. Newton and Miah note that although most educators believe in the utility of learning preferences, only about one-third actively apply them in practice, suggesting that pedagogical strategies grounded in evidence may be more impactful than adherence to preference categorisations [32]. Hattie further emphasises that while learning preferences remain attractive due to their simplicity and the sense of individualised instruction, the research consensus favours adaptable strategies that cultivate critical thinking, self-regulation, and problem-solving over tailoring instruction to presumed learning preferences [40].

As Robert Loo suggests, educators should employ a variety of learning methods and encourage students to remain open to different strategies [41]. This flexibility can allow for a more personalised and inclusive learning experience. Integrating flexible learning strategies alongside awareness of student preferences may therefore be essential. Evidence shows that while learners with converger and assimilator tendencies might respond positively to structured and visual approaches, diverger and accommodator learners may benefit more from

collaborative, experiential, and hands-on activities. This study supports these insights by suggesting that visual and sequential methods appear to support comprehension and retention, particularly for sustainable innovation, whereas entrepreneurial innovation may benefit from auditory and experiential strategies, including workshops, discussions, and real-world case analysis.

By combining structured visual methods with opportunities for active experimentation, reflection, and social interaction, educators can create more inclusive, adaptable, and preference-aligned learning experiences. Such approaches may not only enhance cognitive understanding but also support scientific empathy, allowing learners to connect with complex socio-environmental systems, consider the consequences of actions for diverse stakeholders, and engage meaningfully with sustainability challenges. This alignment of evidence-based strategies with learning preferences suggest support for the development of both cognitive and affective skills in STEAM contexts, potentially promoting innovative, reflective, and responsible decision-making.

Cultural Differences in Learning Preferences

Cross-cultural research suggests that students' learning preferences may be influenced not only by individual cognitive preferences but also by cultural contexts. Studies using Kolb's Learning Preference Inventory and frameworks [27], [42] such as the GLOBE study indicate that cultural dimensions, such as collectivism, uncertainty avoidance, future orientation, and gender egalitarianism, may play a role in shaping whether learners prefer abstract conceptualisation, reflective observation, or active experimentation [43]. Similarly, empirical analyses of cross-cultural differences in learning preference suggest that specific cultures may be associated with distinct learning preferences and abilities, indicating that cultural background can guide how students approach learning tasks [44]. While some universal tendencies exist, such as the appreciation of visual aids and structured explanations, the emphasis on collaborative, hands-on versus structured, analytical learning may vary across nations. In addition, employers in different countries have varying expectations regarding the competencies that students should possess, including sustainability and innovation skills, which further influences the skills that students need to develop during the education process [45]. Recognising these cultural and economic patterns is crucial for designing educational materials and digital learning content that are preference-aligned, relevant, and engaging for international audiences, accommodating diverse ways of processing, reflecting, and applying knowledge.

Building on this theoretical background, the findings of the present study provide insight into how cultural tendencies may manifest in specific European contexts. The findings of this study suggest that while visual aids and structured explanations are universally appreciated, there are clear cultural differences in how students tend to prefer learning. Countries like France and Norway appear to emphasise collaborative, hands-on learning, whereas Belgium and Spain may lean more towards structured and interactive formats. Slovenia, with its balanced preferences, reflects the value of integrating multiple methods to cater to diverse needs. Recognising these cultural nuances may be essential for creating educational content that resonates with international audiences. This is especially relevant when considering global social media platforms like YouTube, Facebook and TikTok, where educational content must appeal to diverse learner preferences. Tailoring content to different cultural and educational contexts enhances engagement, promotes scientific empathy, and supports preference-aligned learning outcomes, particularly for sustainability and innovation education.

These findings are particularly important in the context of internationalised higher education. Given that most HEIs include international students from diverse cultural backgrounds, it is crucial that learning materials integrate elements that accommodate a range of cognitive and metacognitive preferences. This is particularly important for digital learning materials, which are accessible worldwide to learners with diverse cultural and educational

backgrounds. The study suggests that preferences for different approaches to learning new concepts appear to vary across EU countries, reflecting broader regional patterns in skill portfolios, with northern and western nations demonstrating stronger socio-cognitive skills (visual and written learning) and southern countries showing comparatively higher sensory-physical skills (hands-on and auditory learning). These patterns highlight the potential need for culturally sensitive learning approaches that combine visual, experiential, and collaborative methods to support preference-aligned, inclusive, and empathetic education.

However, cultural dimensions alone cannot fully account for the observed differences. Several factors may explain the observed differences in learning preferences among students from different countries. Cultural dimensions such as individualism vs. collectivism, uncertainty avoidance, and power distance can shape how students approach learning tasks and interact with peers and instructors, influencing their preference for collaborative, hands-on, or structured learning [46]. However, comparative research indicates that learning preferences cannot be explained by culture alone, but are shaped by complex interactions between educational context, disciplinary background, institutional practices, and students' developmental stage [47]. Learning patterns are also not fixed but adaptable; students' strategies, conceptions, and orientations may change in response to instructional design, assessment methods, and the broader learning environment. This suggests that well-designed learning environments can foster more constructive and self-regulated learning approaches regardless of cultural background. Therefore, the differences observed between countries in the present study should be interpreted as context-dependent tendencies rather than static cultural traits.

In addition to cultural and pedagogical influences, structural and socioeconomic factors may further shape learning preferences. Exposure to technology and digital learning tools, as well as prior experience with sustainability and entrepreneurship topics, could further shape students' engagement and preferred learning modalities. Socioeconomic factors and the pedagogical culture within each HEI may also influence whether students favour visual, auditory, or experiential learning, reflecting both institutional practices and broader cultural norms [48]. Differences in access to educational resources, parental educational background, and levels of academic support may further contribute to variation in cognitive development, self-efficacy, and learning strategies. Students from lower socioeconomic backgrounds may experience additional stressors related to financial insecurity or limited access to technology, which can affect concentration, motivation, and adaptability in learning environments. At the same time, disparities in education funding, teacher practices, and peer academic culture across institutions and countries may shape students' expectations, participation patterns, and responsiveness to different instructional formats. Finally, the intersection of cultural norms and socioeconomic conditions may produce unique learning adaptations, meaning that observed differences in this study likely reflect a combined effect of cultural, structural, institutional, and psychological factors rather than any single explanatory variable.

Given these multiple interacting influences, it is also important to clarify the methodological positioning of the present research. This study was designed as an exploratory and descriptive investigation of students' learning preferences across multiple European higher education institutions. Given the use of a convenience sampling approach and the non-probabilistic nature of the sample, the primary aim was to provide a descriptive overview rather than to test causal relationships or statistically significant differences between countries, topics, or institutions. Consequently, the results are reported using percentages and figures, and comparative interpretations are presented cautiously. The study is therefore positioned as a descriptive exploration of learning preferences, rather than a comparative study relying on inferential statistics. This limitation suggests that the findings should be interpreted with caution, and future research could expand the study by using larger, probabilistic samples, including additional demographic variables (e.g. gender, age, study level, past experiences), and applying inferential statistical methods. Such an extension would allow for more robust

comparisons across countries, HEIs, and topics, enhancing the generalisability and explanatory power of the results.

CONCLUSION

This study provides insights into the diverse cognitive, metacognitive, and emotional learning preferences of higher education students across five European countries. Visual and sequential learning appeared as dominant cognitive and metacognitive preferences, while hands-on and experiential approaches were generally preferred in fostering emotional engagement and understanding of complex topics, such as sustainable innovations. Taken together, these results indicate that cognitive structure and emotional engagement do not necessarily rely on the same instructional formats. Preferences varied across contexts: sustainable innovation appeared to benefit from visual and practical methods, whereas entrepreneurial innovation tended to favour auditory and interactive approaches. This contextual variation highlights the importance of aligning instructional design not only with learners' cognitive processing styles but also with the specific nature of the subject matter. These findings suggest the need for subject-specific instructional strategies that align with cognitive processing and affective engagement to enhance learning outcomes.

Beyond subject-related differences, broader regional patterns also emerged. Cross-cultural differences also seem to influence learning preferences, with northern and western European students showing a tendency towards socio-cognitive approaches (visual and written) and southern European students appearing more inclined toward sensory-physical approaches (hands-on and auditory). Such tendencies, while not absolute, point to the relevance of culturally responsive instructional design in international higher education. Integrating visual, practical, and collaborative methods in educational design may accommodate these variations, potentially promote scientific empathy, and support inclusive, adaptable, and preference-aligned learning experiences.

Importantly, these cross-cultural tendencies should not be interpreted as fixed or deterministic characteristics. Learning preferences appear to be shaped by a dynamic interplay of cultural norms, socioeconomic conditions, institutional practices, disciplinary contexts, and exposure to specific pedagogical approaches. Moreover, learning patterns are adaptable and may evolve in response to instructional design, assessment strategies, and the broader learning environment. In this sense, educational contexts do not merely reflect preferences—they actively contribute to shaping them. This suggests that thoughtfully designed educational settings—particularly in digital and international contexts—have the potential to foster more constructive, self-regulated, and inclusive learning approaches regardless of students' cultural or socioeconomic backgrounds. Overall, by situating learning preferences within this broader cultural, structural, and pedagogical framework, these insights can inform the development of digital and international learning environments that balance evidence-based pedagogy with culturally sensitive, student-centred approaches.

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