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Enhancing Sustainability Competence: A Case Study of Physics and Mathematics Curricula at the University of Maribor

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Sustainability competence is increasingly recognized as a vital skill for addressing global environmental challenges. As societies transition to sustainable energy solutions, individuals must acquire the knowledge and skills to make informed decisions. According to the European sustainability framework GreenComp, competences supporting green transition are categorized into embodying sustainability values, embracing complexity, envisioning sustainable futures and acting for sustainability. This study examines the development of sustainability competence within the Physics and Mathematics programs at the Faculty of Natural Sciences and Mathematics University of Maribor. The analysis focuses on compulsory and elective courses to evaluate how curricula have adapted to challenges and market needs. Additionally, the evolution of teaching methodologies and their impact on students' understanding of sustainability is assessed. Closed-ended questionnaires were distributed to measure graduates' perceived sustainability competence. The findings indicate graduates are confident in critical thinking and problem-solving. However, fewer than a third felt adequately informed about energy policies and the circular economy. Furthermore, only half reported sufficient knowledge of energy-saving practices, energy sources, sustainability concepts, and energy efficiency. The results highlight that while the curricula successfully foster general skills in critical and exploratory thinking, greater emphasis is needed on specific topics, particularly energy policies and sustainability practices.

Keywords: sustainability, higher education, curriculum analysis, graduate competences, questionnaire

Introduction

The green transition and digital transformation represent two of the most pressing and interconnected global challenges of the 21st century. Their growing influence is reflected in the increased expectations placed on educational systems worldwide, particularly on higher education institutions, which are expected to not only transmit disciplinary knowledge but also foster the critical competences needed to navigate and shape sustainable futures.

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In response to accelerating environmental degradation, energy crises, and social inequalities, the European Union has launched several strategic frameworks, most notably the European Green Deal and the Digital Agenda for Europe. These initiatives aim to promote a just and inclusive transition toward a climate-neutral, resource-efficient, and digitally empowered society (European Commission, 2019; 2020). Within this vision, education, especially higher education, plays a crucial enabling role by equipping current and future professionals, educators, and decision-makers with the competences necessary for system-wide transformation.

Traditional curricula in science and mathematics, while foundational, often remain content-heavy and decontextualized, focusing predominantly on theoretical knowledge and procedural skills. However, in the face of complex global crises such as climate change, biodiversity loss, and the energy transition, this approach is no longer sufficient. Instead, there is a growing need to shift toward competence-based education, where students not only acquire knowledge but also develop values, dispositions, and action-oriented skills necessary for sustainability and resilience (UNESCO, 2020).

One of the most comprehensive conceptual tools to support this educational transformation is GreenComp – The European Sustainability Competence Framework (European Commission, Joint Research Centre, 2022). Developed by the European Commission's Joint Research Centre, GreenComp defines 12 interrelated sustainability competences, structured into four interconnected clusters:

1. Embodying sustainability values, which involves cultivating a sense of justice, equity, responsibility, and respect for all forms of life.
2. Embracing complexity, which refers to systems thinking, critical reflection, and the ability to deal with uncertainty and interdependence.
3. Envisioning sustainable futures, which include creative imagination, foresight, and the ability to generate transformative alternatives.
4. Acting for sustainability, which emphasizes individual and collective agency, political literacy, and the capacity to initiate and sustain change.

GreenComp is intentionally designed as a conceptual and non-prescriptive framework, making it adaptable across diverse educational levels, national contexts, and disciplinary domains. However, for its effective implementation, it requires systemic changes in curriculum design, pedagogical practice, and assessment culture—especially in traditionally discipline-centered fields such as physics and mathematics, where sustainability themes have often been underrepresented.

Within this context, the Faculty of Natural Sciences and Mathematics at the University of Maribor (FNM UM) initiated a pilot research project to critically evaluate the current integration of sustainability and digital competences into its Physics and Mathematics study programs. In addition to these academic tracks, the project also examined the Subject Teacher study programs (Educational Physics and Educational Mathematics), recognizing the crucial role they play in preparing future physics and mathematics teachers to address sustainability challenges and digital transformation in education. The project responds to the urgent need to understand how natural science and STEM education can be better aligned with the goals of sustainability and digital transformation.

The core research question guiding this study is: *To what extent do the current curricula foster competences that are consistent with the GreenComp framework and meet the evolving expectations of the 21st-century labor market?*

To address this question, the research team conducted a comprehensive curriculum mapping and quantitative competence assessment using validated instruments aligned with GreenComp and DigComp 2.2 frameworks. The resulting analysis provides empirical evidence of both strengths and gaps in the current educational approach and offers practical recommendations for future curricular reforms.

Ultimately, this study contributes to the emerging body of knowledge on how physics and mathematics education can play a transformative role in achieving sustainability goals, not only through disciplinary excellence but also through transdisciplinary, ethically grounded, and action-oriented learning.

Literature Review

The challenges identified in the curricula of Physics and Mathematics programs at FNM UM, particularly the underrepresentation of socio-political and action-oriented sustainability competences, are not unique to Slovenia. Similar findings have been reported across several EU member states, indicating a broader systemic issue in the integration of sustainability in higher education, especially within STEM disciplines.

For example, Leal Filho, Shiel, & do Paço, (2016) conducted a multi-country study analyzing sustainability integration in European universities and found that while environmental awareness among STEM students was generally high, competences related to civic engagement, policy literacy, and interdisciplinary collaboration were significantly weaker. This reflects a persistent imbalance between cognitive and affective-behavioral dimensions of sustainability learning.

A detailed examination by Mokski, Leal Filho, Sehnem, & Salgueirinho Osório de Andrade Guerra, (2022) also revealed that engineering and science students often perceived sustainability as a technical challenge, lacking a deeper understanding of its ethical, political, and societal dimensions. Similarly, Rieckmann (2016) emphasized that without pedagogical strategies that actively promote systemic thinking and value-based reflection, students struggle to translate sustainability knowledge into transformative action.

While the cognitive and technical aspects of sustainability are commonly emphasized, there is increasing recognition that digital competence also plays a critical role in shaping students' ability to engage with complex sustainability issues. As Vuorikari, Kluzer & Punie (2022) suggest in the DigComp 2.2 framework, future-oriented education must develop not only digital literacy for information processing but also digital creativity, collaboration, and ethical awareness. However, research (Selwyn, 2021; Sterling, 2019) warns that current digital integration in STEM curricula often remains instrumental, focusing on technical efficiency rather than on fostering reflective and transformative digital agency for sustainability. Furthermore, a study by Dias-Trindade & Moreira (2023) revealed that integrating digital technologies into formal education relies strongly on funds, opportunities for teacher training, and teachers' perceptions.

In the context of teacher education, the TEESNet project (Ferreira, Evans, Davis & Stevenson, 2019) compared approaches across multiple EU countries and concluded that while frameworks such as GreenComp offer valuable conceptual guidance, their implementation remains superficial unless accompanied by institutional commitment, interdisciplinary teaching teams, and authentic learning environments linked to real-world challenges.

Furthermore, Glover (2023) argued that despite widespread recognition of Education for Sustainable Development (ESD) in policy, its practical realization in higher education curricula tends to be fragmented and discipline bound. This observation aligns with the findings of the present study, where sustainability content is not structurally embedded across core modules but is instead isolated in elective or project-based activities.

These comparisons underscore that the situation at FNM UM is reflective of a pan-European pattern, one in which STEM education is advancing in scientific depth but often lags in transformative capacity. They also point to the urgent need for systemic curriculum redesign that bridges the divide between technical expertise and societal responsibility, particularly in light of global policy agendas such as the European Green Deal and the UN Sustainable Development Goals (SDGs).

These findings resonate with the broader call for transformative education articulated in UNESCO (2020), which urges higher education institutions to move beyond knowledge acquisition and toward fostering sustainability action. Mezirow's (2000) theory of transformative learning further supports this, emphasizing the importance of critical reflection and perspective shifts in enabling students to act as change agents. In this light, STEM faculties must not only adopt frameworks such as GreenComp or DigComp as reference tools but also integrate them into institutional strategy, faculty training, and course-level learning outcomes. Without such alignment, sustainability education risks remaining rhetorical rather than reformative.

A recent study conducted as part of the FORM-STEMA project at the University of Maribor in 2025 supports these broader European trends. The findings reveal that while final-year students demonstrate relatively strong knowledge of basic energy concepts, their understanding of sustainability policies and the ability to make interdisciplinary connections remain underdeveloped. This aligns with earlier research highlighting fragmented curricular approaches and underscores the need for harmonized, cross-sectoral pedagogical strategies that build system-level competences for sustainability.

This aligns with Sterling's (2011) concept of *anticipative education*, which advocates preparing learners not merely for existing roles, but for future complexity and uncertainty. Anticipative education emphasizes foresight, adaptability, and value-driven decision-making, qualities that are increasingly necessary in navigating sustainability challenges in the Anthropocene. Embedding such forward-looking approaches into science education can help bridge the gap between technical expertise and the civic imagination required for transformative action.

Methodology

This study employed a quantitative research approach based on structured survey questionnaires designed to assess self-perceived sustainability and digital competences among students and academic staff (program coordinators). The aim of the research was to determine how effectively the current study programs develop competences as defined in the European reference frameworks GreenComp (European Commission, Joint Research Centre, 2022) and DigComp 2.2 (Vuorikari, Kluzer & Punie, 2022).

Research Instruments

The questionnaires were constructed using indicators derived from the aforementioned frameworks and included Likert-type scales measuring:

- Sustainability competences: knowledge of energy sources, energy efficiency, systems thinking, understanding of policies, and sustainable behavior (based on GreenComp), assessed using a traditionally applied 5-point Likert scale;
- Digital competences: searching, evaluating, and managing information, creating digital content, collaborating via digital tools, and applying ethical and safety standards (based on DigComp 2.2), measured using 8-point Likert scale corresponding to the eight levels of digital skill achievement outlined in DigComp 2.2.

The questionnaire was divided into several thematic sections: (1) general demographic information, (2) self-assessment of competences, (3) perception of the curriculum, and (4) suggestions for improvement. Instrument validation was conducted during the preliminary project phase through expert group consultation and internal pilot testing.

Sample

The sample consisted of final-year students enrolled in the Physics, Mathematics and Subject Teacher Education programmes at the Faculty of Natural Sciences and Mathematics, University of Maribor. A total of 28 students participated in the study. In addition, 4 programme coordinators from both pedagogical and non-pedagogical tracks were included to enable a comparative perspective between students' and coordinators' perceptions of competence development.

The relatively small sample size is explained by the fact that the target population itself is limited, as each study programme has a small cohort of final-year students. Since participation was voluntary and focused exclusively on graduating students at the end of their study cycle, the number of eligible respondents was naturally small but representative of the entire population of the programmes examined.

In order to obtain a broader and more contextually grounded understanding of sustainability competence development in STEM fields, a cross-faculty comparison was included in the research design. The Faculty of Civil Engineering, Transportation Engineering and Architecture (FGPA UM) was selected as a reference group because it offers STEM-related study programmes with partly overlapping competence goals, yet with a different disciplinary focus. Including this comparison enabled us to examine whether the identified competence patterns at FNM UM were discipline-specific or reflected wider trends across STEM education. Therefore, the comparison with FGPA UM was planned as an integral part of the methodological design, and not only introduced at the stage of analysing the results.

Data Analysis

Data were statistically analyzed using SPSS software (version 27). The following analytical procedures were applied:

- Descriptive statistics: means, standard deviations, and frequency distributions to characterize competence levels across various dimensions;
- Correlation analysis (Pearson's r and Spearman's ρ): to measure the relationship between student and coordinator assessments and to identify agreement in perceived competences;
- Cohen's d: to evaluate effect sizes and the practical significance of observed differences;
- 95% confidence intervals: to assess the reliability of the results;
- Paired t-tests: to determine statistically significant differences in mean ratings between groups (e.g., students vs. coordinators; pedagogical vs. non-pedagogical programs). Although the sample size was relatively small, the use of the t-test was considered appropriate for this analysis. The t-test is robust to violations of normality, particularly when group sizes are small and relatively equal, as was the case in this study. Prior to conducting the t-tests, the assumptions of normality and homogeneity of variances were examined and met. In addition, the t-test was selected due to its suitability for comparing mean values between two groups and its widespread application in educational and social science research. Non-parametric alternatives (e.g., Mann-Whitney U test) were considered; however, these are less powerful when assumptions for parametric testing are satisfied, hence the t-test was deemed the most appropriate method for the research design and data structure.

Statistical significance was evaluated at the $\alpha = 0.05$ level. In cases where significance thresholds were not met, borderline effects were interpreted, and recommendations for further studies with larger samples were provided.

To ensure the credibility and robustness of the findings, several validation procedures were applied. The internal consistency of the survey scales was examined, and descriptive and inferential statistical analyses were used to verify the coherence of response patterns across participant groups. Triangulation was achieved through a combination of methods:

- data triangulation, by comparing responses from students and programme coordinators;

- methodological triangulation, combining quantitative survey results with curriculum analysis; and
- source triangulation, by comparing selected indicators with data from a parallel study conducted at the Faculty of Civil Engineering, Transportation Engineering and Architecture (FGPA UM).

This multi-level triangulation approach strengthened the reliability of the findings and enabled a more comprehensive interpretation of competence development across programmes.

Ethical Considerations

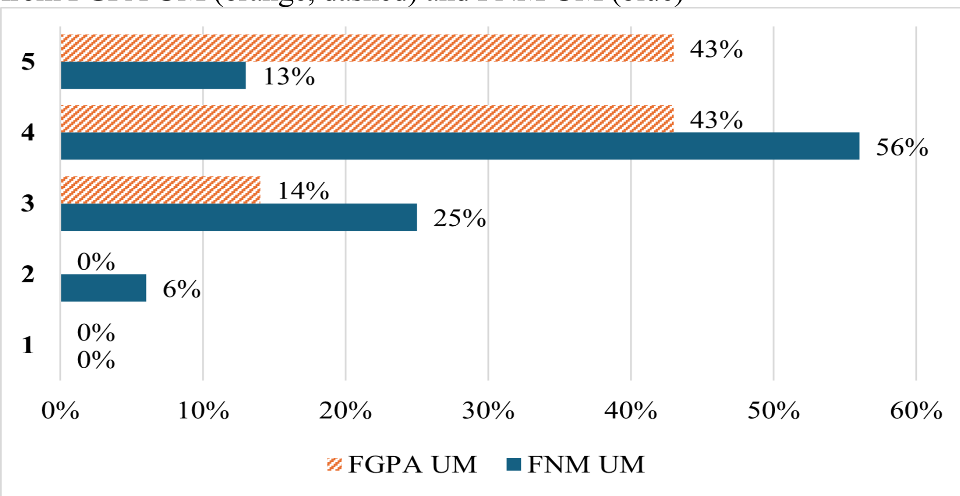
The study was conducted in accordance with the ethical guidelines of the University of Maribor. All participants took part voluntarily and anonymously. The collected data was used exclusively for research purposes.

Results

Energy Literacy and Understanding of Sustainability Concepts

A detailed survey conducted in May–June 2025 among final-year students at FNM UM (N = 28) provided additional insight into specific dimensions of sustainability competence Students evaluated their knowledge and attitudes using a 1–5 Likert scale, where 1 meant "strongly disagree" and 5 "strongly agree". As shown in Figure 1, the highest average score was recorded for understanding energy sources (M = 4.34), followed by efficient energy use (M = 4.30) and sustainable energy production (M = 4.11). These values confirm a strong foundation in core energy-related topics. We compared results with responses of final-year students at FGPA UM.

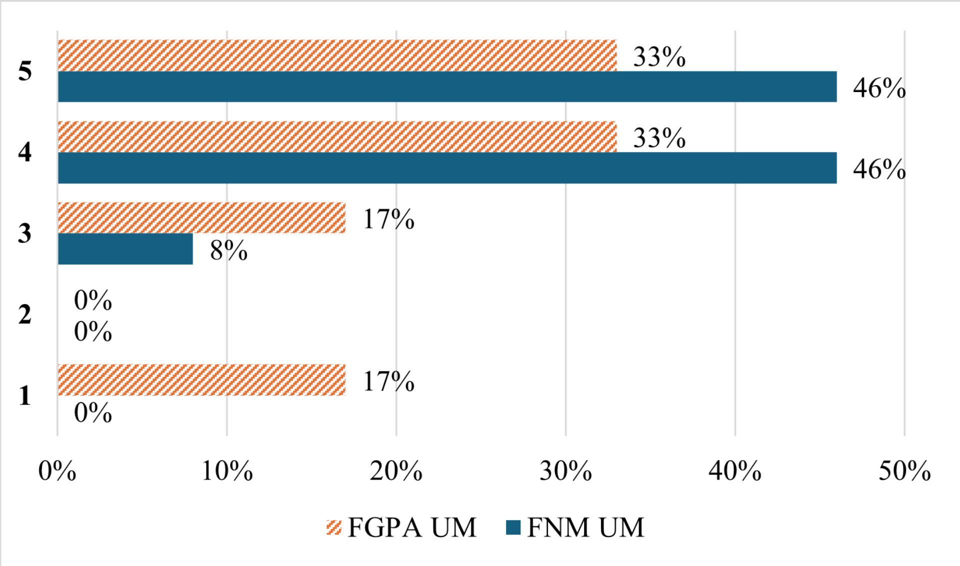
Figure 1. Recognition of Cause-and-Effect Relationships: Results of Student Responses from FGPA UM (orange, dashed) and FNM UM (blue)



Source: own.

In contrast, substantially lower ratings were reported in areas concerning systemic and policy knowledge. Understanding of the circular economy received a mean score of 3.61, while awareness of energy legislation and regulation was rated at only M = 3.32. As presented in Figure 2, students' self-perceived ability to critically evaluate energy policy was also low (M = 3.39), indicating a need for curricular reinforcement in these domains.

Figure 2. Recognition and Application of Measures for Sustainable Resource Management: Results of Student Responses from FGPA UM (orange dashed) and FNM UM (blue)



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Survey results from students at the Faculty of Natural Sciences and Mathematics, University of Maribor (FNM UM), indicate a moderate to high level of self-assessed understanding of basic energy concepts, including energy sources, efficiency, and consumption. Average ratings ranged from 3.7 to 4.1, suggesting that the study programs provide a solid foundational understanding of energy-related science.

However, notable knowledge gaps were identified in more systemic and policy-related topics—such as energy legislation, circular economy, and sustainable development policies. Less than one-third of students rated themselves as adequately informed in these areas. These results point to a limited integration of socio-political and ethical dimensions of sustainability into the curriculum, a trend similarly highlighted in the European GreenComp framework (European Commission, Joint Research Centre, 2022).

A comparative visualization of competence ratings across different sustainability dimensions is presented in Figure 3 (based on student responses), showing both strength in foundational concepts and gaps in applied and policy-relevant domains.

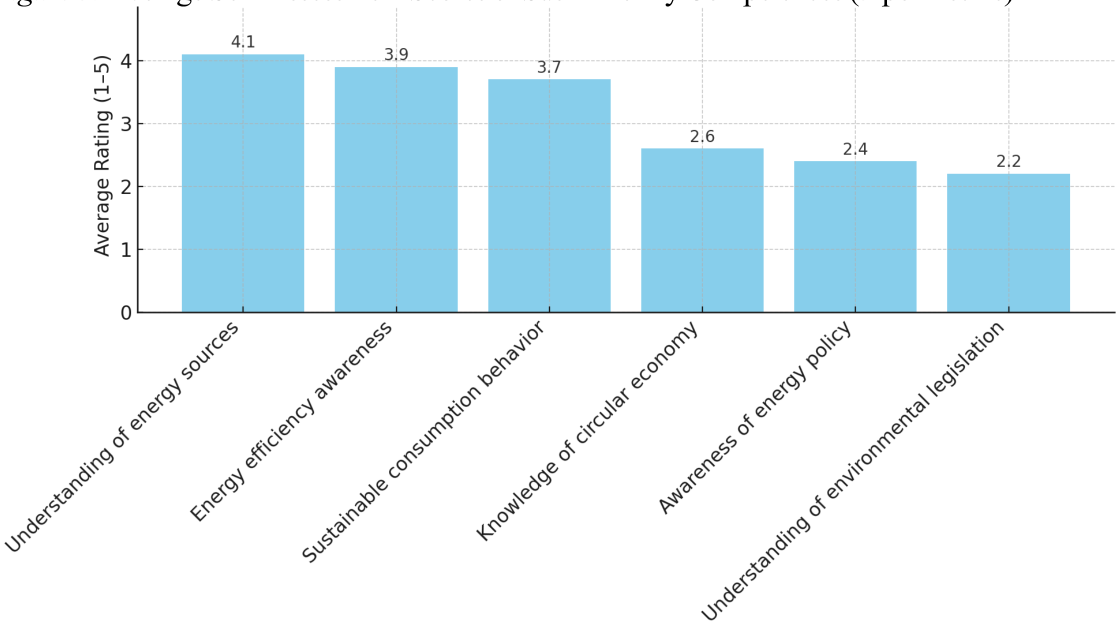
Additional indicators from the survey offer further insight into specific competence areas. For instance, average self-assessment of causal reasoning in energy systems was 3.9/5 among FNM UM students, slightly higher than the 3.4/5 reported by FGPA UM students (Figure 1).

In terms of understanding the circular economy, only 31% of FNM students agreed or strongly agreed with the relevant statement (score of 4 or 5), highlighting a gap in interdisciplinary sustainability knowledge (Figure 2).

Similarly, comprehension of green business principles received the lowest average rating (3.2/5), despite the increasing relevance of these concepts in sustainability education (Figure 3).

These findings point to both strengths and blind spots in current curricular approaches.

Figure 3. Average Self-Assessment Scores of Sustainability Competences (5-point scale)



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Statistical Analysis of Program Coordinator Perspectives

A comparative analysis of sustainability competence ratings among various study program coordinators revealed statistically significant differences. Particularly noteworthy is the difference between the coordinator of the pedagogical physics program and the coordinator of the non-pedagogical physics program, where the variation in ratings was statistically significant ($p = 0.028$). This suggests differing perceptions of competence development depending on whether the program is pedagogically or professionally/research oriented. Pedagogical programs may place less emphasis on specific content related to policy, legislation, and practical applications, which could hinder the development of applied competences among students.

Alignment between Students and Program Coordinators

One of the most positive findings is the high level of agreement in competence perceptions between students and the coordinator of the non-pedagogical program

($r = 0.806$; $p < 0.001$). This alignment indicates a shared understanding of competence development within the program. Such consistency is valuable, as it reflects transparent and effective communication between educators and learners. In contrast, correlation with the pedagogical program coordinator was weaker, which may indicate a need for improved reflection on learning outcomes and self-evaluation practices.

Digital Competences (DigComp 2.2)

Students' digital competences were assessed using the DigComp 2.2 framework, where self-assessment used an 8-point Likert scale. Results reveal high levels of digital literacy in basic areas such as:

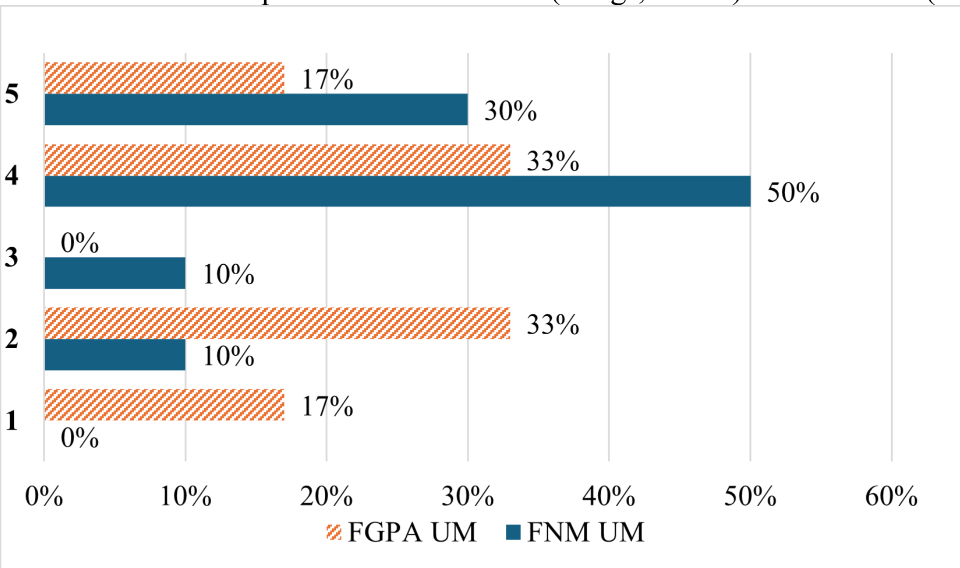
- Information and data literacy (average = 7.1/8)
- Communication and collaboration (average = 6.8/8)

However, notable gaps remain in more creative and productive dimensions. Specifically:

- Creating digital content: average score = 4.0/8
- Programming and innovation using digital tools: average score = 3.7/8

These trends are confirmed by response frequencies: 82% of students felt confident using digital tools for searching and evaluating information, but only 36% in digital content creation and just 18% in applying digital tools across interdisciplinary sustainability contexts (see Figure 4).

Figure 4. Understanding the Basics of Green Business and Sustainable Entrepreneurship: Results of Student Responses from FGPA UM (orange, dashed) and FNM UM (blue)



Source: own.

These results underline a need to shift from passive to active digital engagement, especially in contexts requiring students to create, model, and communicate sustainability-related solutions. This shortfall is increasingly relevant given the growing emphasis on creative digital practices in both education and the labor market (Vuorikari et al., 2022). Similarly, Atanas (2018) found that the use of virtual-physical and physical-virtual manipulatives in physics classes significantly enhances students' active engagement and promotes deeper conceptual understanding.

Final-year students rated their competence highest in technical areas, while lower scores were reported for policy and systems-based sustainability dimensions.

A more granular analysis of the survey data reveals patterns in specific competence areas. Figures 1 through 4 illustrate student self-assessments across various dimensions of sustainability and digital competence. Students generally rated themselves highly in foundational scientific knowledge and digital information processing (Figure 1) but demonstrated lower confidence in applying knowledge to real-world contexts, such as identifying sustainability strategies, understanding green business and entrepreneurship, or engaging in interdisciplinary collaboration. This gap between theoretical understanding and applied sustainability action highlights the need for curricular designs that better integrate civic, economic, and digital dimensions.

Discussion

The results of the analysis indicate that study programs at the FNM UM effectively develop general academic competences, such as critical thinking, analytical problem-solving, and digital literacy, particularly in the context of information retrieval and processing. These competences form the core of modern university education and align with the 21st-century competence framework (OECD, 2025).

However, the data also reveal significant gaps in content-specific sustainability competences, particularly in dimensions related to the socio-political context, practical knowledge application, and active engagement for sustainability. Students report limited knowledge of energy policy, the circular economy, and systemic aspects of sustainability, which is inconsistent with the goals of the GreenComp framework, especially its pillars *"acting for sustainability"* and *"embracing complexity"* (European Commission, Joint Research Centre, 2022). The inclusion of final-year FNM students in the 2025 survey further strengthens our findings. The comparatively high scores in areas such as systems thinking about energy systems (mean 6.7) and renewable technology analysis (mean 6.9) demonstrate an encouraging alignment with the intended learning outcomes of STEM-integrated sustainability education. These two areas also received the lowest self-assessment ratings, indicating a lack of integrated, applied approaches in the curriculum. These differences are visually illustrated in Figure 3, which shows that competences such as understanding of energy sources are rated significantly higher than those related to policy or systems thinking.

Pedagogical strategies that remain primarily focused on theoretical content delivery are no longer sufficient in light of the rapidly evolving climatic, societal, and technological challenges. Sustainability-oriented education requires a transdisciplinary approach that transcends traditional divisions between the natural and social sciences and enables students to develop competences for real-world problem solving (Sterling, 2001; UNESCO, 2020).

The findings on limited creative use of digital tools (e.g., digital content creation), which students rated significantly lower (4.0/8), further support the need to shift from passive consumption of technology to active, collaborative, and problem-based use. This includes the use of digital tools for data visualization, environmental scenario simulation, and co-creation of knowledge—tools that support GreenComp competences and simultaneously foster student autonomy.

Additionally, the observed statistical difference between pedagogical and non-pedagogical physics programs ($p = 0.028$) suggests structural variation in how sustainability content is embedded depending on the academic orientation. This highlights the importance of ensuring horizontal integration of sustainability competences across study tracks.

The strong correlation between students' self-assessments and the evaluations of the non-pedagogical program coordinator ($r = 0.806$, $p < .001$) reflects well-structured learning outcomes and effective internal communication of competence goals.

From a curriculum development perspective, this calls for a comprehensive reform that would:

- systematically integrate sustainability and digitalization themes into core curricula;
- support the development of competences for civic and political engagement (e.g., agency, collective action);
- implement active pedagogical approaches such as project-based learning, case studies, simulations, and problem-based learning (PBL);
- encourage cooperation with local communities and real-world projects, allowing students to understand sustainability as a practical and participatory process, not merely a theoretical concept.

Finally, it is important to stress that these findings are not unique to FNM UM but reflect broader trends and challenges in higher education across Europe, which is still in the early stages of embedding sustainability competences. Studies such as this one have dual value, as tools for institutional self-evaluation and as scientific contributions to the development of sustainability pedagogy.

While digital literacy is often integrated into STEM education through basic competencies such as information retrieval and data processing, the creative dimension of digital competence remains significantly underdeveloped, as indicated by the lower self-assessment scores in this study. The European Digital Competence Framework (DigComp 2.2) highlights *"creating digital content"* and *"collaborative digital production"* as key areas that support innovation, communication, and critical engagement with digital tools (Vuorikari et al., 2022). However, these aspects are frequently marginalized in STEM curricula that prioritize correctness, technical precision, and individual problem-solving over open-ended exploration.

To enhance digital creativity in physics and mathematics education, a paradigm shift is needed, from instrumental use of digital tools to their transformative and expressive use. This involves embedding tasks that encourage students to:

- Design simulations and models to represent complex systems (e.g., energy flows, planetary boundaries).
- Produce multimedia content, such as educational videos, infographics, or podcasts, that communicate scientific concepts to broader audiences.
- Use collaborative platforms (e.g., GitHub, Miro, Padlet) for co-creating knowledge, designing experiments, or developing open-source tools with societal impact.
- Engage with digital storytelling, linking data analysis with narrative structures that humanize scientific knowledge and give voice to ethical dimensions of sustainability.

Such activities can be embedded into coursework through project-based learning (PBL), interdisciplinary hackathons, or challenge-based modules that address real-world problems through creative digital outputs. Importantly, educators must be supported through professional development to integrate these practices without compromising disciplinary rigor.

As one student noted, "I understand energy efficiency now, but I don’t yet feel confident applying it to everyday decisions." Another remarked, "We need more real-world projects, not just formulas and theory. That’s when learning becomes real."

By strengthening digital creativity, STEM curricula not only become more engaging and relevant to students' future careers but also contribute to the development of transformative digital agency, the ability to use technology not only to solve problems, but to imagine and shape sustainable futures.

While the findings of this study provide valuable insights into the development of sustainability and digital competences within STEM curricula, several limitations should be acknowledged to contextualize the results and guide future research.

First, the sample size was limited to final-year students and program leaders at a single institution, FNM UM, which may constrain the generalizability of the results. Although the sample was representative of the relevant academic programs within the faculty, broader comparative data from other institutions or faculties (e.g., engineering, social sciences) would enhance the robustness and external validity of the conclusions.

Second, the study relied on self-assessment questionnaires, which are inherently subject to social desirability bias and subjective interpretation. Respondents may over- or underestimate their competences due to a lack of objective benchmarks or varying levels of metacognitive awareness. While validated scales and triangulation with curriculum analysis were used to mitigate these effects, the inclusion of performance-based assessments or external evaluations in future studies would improve data accuracy.

Third, the cross-sectional nature of the survey provides a snapshot of perceived competence at a single point in time. A longitudinal design, capturing students’ progression throughout their academic journey, would offer deeper insight into how competences are developed across courses and semesters.

Lastly, although the GreenComp and DigComp frameworks provide comprehensive reference points, their integration into specific disciplinary contexts—such as mathematics and physics—remains methodologically complex. Further refinement of discipline-specific indicators would help bridge the gap between general competence frameworks and concrete curricular outcomes.

By acknowledging these limitations, this study encourages cautious interpretation of the findings and highlights areas for future research and institutional development.

Conclusion

The analysis of the Physics and Mathematics study programs at the Faculty of Natural Sciences and Mathematics, University of Maribor shows that these programs have already successfully fostered some key academic and digital competences. However, in the context of the demands posed by the green transition, there are notable gaps in competences, particularly regarding understanding of energy policies, circular economy principles, and the capacity for sustainability action in broader societal contexts.

To comprehensively strengthen sustainability competences, we propose the following strategic directions, grounded in empirical findings and consistent with European guidelines (European Commission, Joint Research Centre, 2022; Vuorikari et al., 2022; UNESCO, 2020):

1. Structural integration of sustainability-related content—including energy, policy, and legislation—into the core components of curricula. Rather than being optional or peripheral, these topics should be systematically included in disciplinary modules to deepen understanding of the intersection between science and society.
2. Development of interdisciplinary learning modules, connecting natural sciences with social sciences, technology, and the arts. Collaboration with other faculties and programs (e.g., economics, sociology, civil engineering, computer science) can significantly contribute to competences such as systems thinking, multiperspective analysis, and sustainable problem-solving.
3. Active student involvement in sustainability-oriented projects based on real-world needs of local communities. This could include engagement in municipal energy strategies, school campaigns for energy efficiency, or environmental monitoring. These approaches, supported by project-based learning (PBL), enhance students' sense of ownership, civic responsibility, and political agency.
4. Implementation of regular competence assessments using standardized tools such as GreenComp for sustainability, DigComp for digital literacy, and the Energy Literacy Framework for energy-related knowledge. These tools enable comparability, monitoring of progress, and curriculum adaptation in response to labor market and societal changes. These frameworks should not only guide individual course design but be embedded into broader institutional strategies—including curriculum reform, staff training, and quality assurance

mechanisms. Future iterations of the program should systematically monitor energy literacy metrics, as recent evidence from the 2025 cohort at FNM UM highlights the critical role of higher education in equipping students with competencies for the green transition.

The successful implementation of these recommendations requires a strategic institutional approach and the support of national policies that recognize sustainability competences as a fundamental component of quality higher education.

Furthermore, aligning study programs with the evolving needs of the labor market and society is essential. As sustainability and digital transformation reshape all sectors—from energy and construction to public administration—graduates must be equipped not only to meet but to lead these transitions. Embedding interdisciplinary and value-driven education enhances both employability and societal resilience.

It is essential that these changes are inclusive, reflective, and geared toward the long-term development of academic communities as key actors in the green and digital transition. In doing so, universities move beyond content transmission and become active laboratories for sustainable futures—training not only professionals, but critical, creative, and courageous citizens of the Anthropocene.

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