A Systematic Review of STEAM Education’s Role in Nurturing Digital Competencies for Sustainable Innovations

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Abstract: This systematic review examines the intricate relationship between Science, Technology, Engineering, Arts, and Mathematics (STEAM) education, digital competence, and sustainable innovations in the context of academic institutions. This study, conducted through a meticulous PRISMA-guided literature review, spans the decade from 2013 to 2023, focusing on publications from the Scopus and Web of Science databases. The NOISE analysis model guides the exploration, emphasizing the Needs, Opportunities, Improvements, and Strengths in upskilling educators for the digital age. By synthesizing findings, this review highlights the multifaceted nature of digital competence, emphasizing its critical role in the knowledge society. Sustainable innovation emerges as a complex yet essential concept for future digital competencies. Key findings underscore the imperative for a continuous upskilling of educators and the transformative potential of STEAM pedagogy in fostering a holistic, transdisciplinary approach to education. The NOISE analysis offers practical insights, paving the way for future research directions, including the development of a robust conceptual framework for STEAM-based pedagogy. This review contributes by adding a culturally sustaining education framework for STEAM, which adds to existing knowledge by elucidating the symbiotic relationship between STEAM education, digital competence, and sustainable innovations, providing a nuanced understanding crucial for navigating the evolving educational landscape.

Keywords: pedagogic practices; digital education; future workforce skills; interdisciplinary learning; culturally sustaining education framework

1. Introduction

In the contemporary landscape of education, the concept of digital competence has emerged as a multifaceted paradigm, encapsulating technical proficiency, critical evaluation, and a motivated engagement with digital technologies [1]. As a pivotal skill in the knowledge society, digital competence is intricately shaped by political and economic factors [2]. The exigencies of the recent pandemic have accentuated the significance of digital competences, especially in the realm of education, unveiling a pronounced digital divide [3]. This has underscored the imperative for educational institutions to bridge the gap between assumed digital abilities and the actual competence of students, positioning them as crucial contributors to its cultivation through pedagogy [4].

In today’s world, where technological breakthroughs and the need for ecologically responsible practices collide, sustainable innovation and digital competency are closely intertwined. These ideas come together when the use of digital technologies and expertise drives creative solutions to ecological, economic, and social problems. In tandem, the notion of sustainable innovation, as articulated by Varma [5], has evolved into a complex construct encompassing ecological, economic, and social dimensions, along with considerations of equity, public participation, and uncertainty. With a mandate for a systems-based decision-making framework and an inclusive approach addressing intra- and inter-
generational equity, sustainable innovation requires a nuanced understanding and application. Larson [6] highlights the catalytic role of entrepreneurship in propelling sustainable innovation, emphasizing the integration of environmental and sustainability considerations into business strategy. Hautamäki [7] further positions sustainable innovation as a potent avenue for addressing “wicked problems”, advocating for impact orientation, systemic thinking, and inclusivity. Seebode (2012) [8] accentuates the necessity for novel approaches to innovation management amidst escalating sustainability pressures and opportunities. Although Industry 4.0 applications for sustainability have garnered much attention lately, more research is still needed to understand how digital transformation and Industry 4.0 technologies support sustainable innovation in sectors like manufacturing, materials, mining, energy, etc. To close this knowledge gap, G Hobakhloo et al. [9] have created a strategic roadmap that details how companies can use Industry 4.0 technology to include sustainability in creative processes that employ digital techniques. Still unresolved is how to build these competencies at different academic levels. These perspectives collectively accentuate the intricate and multifaceted nature of sustainable innovation, necessitating an inclusive, multidisciplinary approach to pedagogy. According to a survey research carried out by Jaki et al. [10] at three Hungarian universities, students and educators saw the value of new digital tools and the curriculum for promoting entrepreneurship significantly embraced information and skills relevant to digitalization. A recent study demonstrates how STEAM instruction may be implemented by university professors of innovation management who do not have a background in the arts and can adapt their lectures for both online and offline learning environments [11].

In academics, STEAM (Science, Technology, Engineering, Arts, and Mathematics) pedagogy has emerged as a promising approach [12]. Pant [13] and Wahyuningsih [14] underscore their potential to elevate teachers’ professional development and early childhood education, respectively. Computational Pedagogy, a pivotal component of STEAM, is explored by Psycharis et al. (2020) [15], introducing the concept of “Computational STEAM Content Pedagogy”. Quigley [16] contributes a conceptual model delineating STEAM teaching practices, emphasizing problem-based delivery, discipline integration, and the cultivation of problem-solving skills. Collectively, these studies underscore the efficacy of STEAM pedagogy in fostering a comprehensive, transdisciplinary approach to education, positioning it as a catalyst for nurturing the digital competencies essential for sustainable innovations.

This literature review endeavors to address three pivotal research questions pertaining to the intersection of digital competency, innovation, and STEAM approach in academic institutions.

RQ1: What kind of digital competencies have been evaluated in the context of sustainable innovation?

RQ2: What challenges and limitations exist in developing digital competence at academic institutions for educators?

RQ3: How can the STEAM pedagogy approach at academic institutions aid in building digital competencies along with its application in the field of sustainable innovation?

Firstly, RQ1 seeks to elucidate the distinctive approaches and findings derived from the last decade of research on digital competency within the context of innovation. By systematically analyzing a curated selection of studies, this review aims to identify and synthesize the novel methodologies and outcomes that have emerged in the past decade, offering an updated understanding of the evolving landscape. Secondly, RQ2 probes into the challenges and limitations inherent in fostering digital competence within academic institutions. Through a critical examination of the existing literature, this review will provide insights into the impediments educational institutions face in developing digital competencies among students. Lastly, RQ3 delves into the potential of the STEAM pedagogy approach in academic institutions, specifically examining how it can contribute to building digital competencies and its application in the realm of sustainable innovation. By exploring empirical studies and scholarly contributions, this review seeks to uncover
the mechanisms through which the integration of STEAM pedagogy enhances digital skills, fostering a workforce capable of addressing the challenges posed by sustainable innovation.

The present study, employing the PRISMA structure [17], will systematically scrutinize a decade’s worth of research on digital competency, innovation, and academic institutions. The results section will present the unique approaches and findings identified, shedding light on the evolving landscape. Subsequently, an in-depth discussion will explore the challenges and limitations impeding the development of digital competency within academic settings, providing nuanced insights. Furthermore, this review will delve into the transformative potential of the STEAM pedagogy approach through a NOISE analysis, unraveling its role in building digital competencies and fostering sustainable innovation. Traditionally used in strategic management, the NOISE model encompasses Needs (N), Opportunities (O), Improvements (I), and Strengths (S), and it is applied in the analysis to achieve triangulation of our investigation. The limitations section will candidly acknowledge the constraints inherent in the selected studies and the review process. Finally, the conclusion will encapsulate the synthesized knowledge, offering practical implications for educational stakeholders and paving the way for future research endeavors in this critical intersection of academia and innovation.

2. Materials and Methods
2.1. Initial Data Collection

In the initial data collection phase for the literature review, the researchers focused on the time frame spanning from 2013 to 2023, employing the keywords “Digital competence” OR “sustainable innovation”. The decision to limit the review to the past decade was driven by the desire to offer a timely and focused analysis that reflects the most current scholarly contributions and developments in the realms of digital competence and sustainable innovation. Utilizing the Web of Science (WoS) and Scopus database, two distinct sources were considered for analysis. The first source, WoS, representing a total of 2148 publications, demonstrated a noteworthy exponential growth trajectory, evolving from less than 100 publications to surpassing 500 within the specified period. Conversely, the second source, Scopus, comprising a total of 4475 publications, exhibited a contrasting trend. Initially peaking at 850 publications in 2014, this source experienced a subsequent decline, reaching approximately 100 publications by 2022, as visually depicted in Figure 1. The rationale behind selecting these sources lies in the comprehensiveness and reliability of the Web of Science and Scopus databases, ensuring a comprehensive overview of scholarly output within the defined temporal scope. The dual-source approach offers a nuanced understanding of the publication trends related to digital competence and sustainable innovation, thereby enhancing the robustness and depth of the ensuing literature review.

![Figure 1](image_url) Visual graph depicting the number of papers published in the Web of Science and Scopus database over the last decade.
2.2. PRISMA Framework

The adoption of the PRISMA framework is underpinned by a commitment to ensuring methodological rigor, transparency, and systematic synthesis of the identified literature. Because PRISMA is structured, it offers a standardized method that is commonly accepted in academic research, making the review process thorough and repeatable. Firstly, PRISMA provides a precise and organized approach to the screening, choosing, and evaluating of the literature. This methodical technique reduces the possibility of bias and improves the review process’s dependability.

Secondly, the PRISMA framework aids in promoting transparency in reporting. It allows for a clear documentation of the various stages of the literature review, from initial data collection to the application of inclusion and exclusion criteria. This transparency is crucial for readers, reviewers, and future researchers to understand the selection process and the basis for our conclusions.

2.2.1. Screening (Inclusion and Exclusion)

The application of the PRISMA approach in this systematic literature review unfolds in a logically structured sequence. In the initial data collection phase, the authors leveraged two reputable sources, Web of Science (WoS) and Scopus, utilizing targeted keywords (“Digital Competence” OR “Sustainable Innovation”). The preliminary results yielded a substantial number of publications, with 2148 from WoS and 4475 from Scopus, reflecting the extensive breadth of research in the field.

Moving to the screening phase, rigorous inclusion and exclusion criteria were applied. The inclusion criteria comprised peer-reviewed articles, conference papers, and reviews published in English, resulting in a refined output of 1604 publications from WoS and 1395 from Scopus. The exclusion criteria further narrowed down the selection by eliminating articles lacking the dual focus on “Innovation” and “Digital Competence”, resulting in 67 publications from WoS and 77 from Scopus since these two prime concepts, “Innovation” and “Digital Competence”, are essential to our argument in this review work. In this study, the authors define “innovation” as the process of implementing new ideas, creating unique products, or improving existing services that generate value for society, the economy, or the environment, whereas we conceptualize “digital competencies” as the set of skills required to effectively use digital technology and tools. This involves not just being able to use digital devices but also having the critical thinking and moral awareness needed for online communication, interacting with digital content, and maintaining cyber security.

2.2.2. Quality Analysis

The subsequent phase involved a qualitative analysis of the literature, where a set of predefined quality criteria were meticulously applied. This qualitative assessment focused on elucidating the concept of digital competence as a skill and its pivotal role in sustainable innovation. The evaluation encompassed research objectives, methodology, instruments employed, major findings pertaining to research questions, research conclusions, limitations acknowledged, and recommendations for future developments in digital competence within the context of higher education. Additionally, future research directions were scrutinized.

A visual representation of the step-wise PRISMA methodology is shown in Figure 2, providing a comprehensive and accessible overview of the systematic review process. This structured approach ensures transparency, rigor, and a methodical synthesis of the pertinent literature, contributing to the scholarly discourse on digital competence and sustainable innovation in higher education.
3. Data Distribution

In this section, brief information is provided regarding the distribution of the data collected through the Scopus database. Figure 3 presents a comprehensive distribution of publications, offering valuable insights into the research landscape on digital competence and sustainable innovation. Regarding subject distribution (3a), it is noteworthy that social sciences, computer sciences, engineering, and business management collectively constitute over 62% of the publication share. This emphasizes the interdisciplinary nature of the research, reflecting the collaborative efforts across diverse academic domains.

Examining document types (3b), the majority, constituting 64%, are articles, followed by conference papers at 20%. An interesting revelation is the limited presence of review papers, accounting for only 4% of the documents. This observation underscores a critical gap in the existing literature, indicating a pressing need for more comprehensive reviews to consolidate and synthesize the evolving body of knowledge in this domain.

The distribution of documents by country (3c) unveils the global footprint of research contributions. Spain emerges as a prolific contributor, surpassing a thousand papers, representing nearly one-fourth of the total publications. Following Spain, Italy, China, the UK, Germany, and Russia exhibit substantial contributions, each with several hundred publications. This distribution underscores the international collaboration and diverse geographical origins of the research.

To enhance the readers’ understanding, the authors have thoughtfully provided a publication density world map (3d), offering a visual representation of the geographical concentration of research outputs. This map contributes to a clearer comprehension of the global dissemination of knowledge in the field of digital competence and sustainable innovation, emphasizing the areas with higher publication density. Overall, Figure 2 encapsulates a multifaceted view of the scholarly landscape, delineating subject prominence, document types, global contributors, and a geographical distribution map for enhanced clarity.
4. Investigating RQ1

In the contemporary institutional landscape, the impact of employee digital competence on the nexus between digital autonomy and innovative work behavior is a pivotal area of investigation. Conventional management education must adapt to the evolving demands resulting from generational shifts and industrial market expectations [18]. A recent study by Huu (2023) [19] has illuminated a positive and significant correlation between digital autonomy and the manifestation of innovative work behavior. This underscores a critical impetus for organizations to not only invest in fostering digital competence and skills among their workforce but also to cultivate a corporate culture that emphasizes autonomy, creativity, and innovation [20].

The European Commission’s elucidation of “digital competence” within the Digital Competence Framework for Citizens (DigComp) [21] further amplifies the discourse. It defines digital competence as the adept, discerning, and responsible utilization and engagement with digital technologies across learning, professional settings, and societal participation. This definition emphasizes the amalgamation of knowledge, skills, and attitudes, reinforcing the multifaceted nature of digital competence.

The Commission’s broader education action plan accentuates the imperative for individuals to be digitally competent, framing it as a contemporary imperative for citizens in the 21st century. Moreover, the Commission has outlined 21 specific skills that constitute the digital competence framework, providing a comprehensive structure for understanding the intricacies of digital skills in today’s context. As the modern world undergoes a profound digital transformation, it becomes increasingly evident that this evolution serves as a principal driver for the development of open innovations [22]. These innovations, facilitating the collection and transfer of knowledge, extend beyond the confines of academic institutions, permeating various sectors of society. Against this backdrop, a thorough analysis of prevalent strategies in innovation becomes indispensable, especially in their correlation with digital tools.
Table 1 is the compilation of relevant strategies and digital tools identified for the sustainable innovation aspects. In the overarching context of the digital transformation shaping the contemporary world, the significance of “sustainability” in new innovations becomes increasingly pronounced. The shortage of fundamental investigations on the elements that support sustainable practices hinders the development of innovative solutions, and the path to sustainable innovation is longer than that of conventional innovation [23]. The symbiotic relationship between digital competence, autonomy, and innovative work behavior extends its impact on the realm of sustainability. Recognizing the imperative for environmentally conscious practices, organizations are now leveraging digital tools and competencies to drive sustainable innovations. As the study delves into the correlation between digital competence and innovative work behavior, it concurrently aims to scrutinize instances where these competencies have been instrumental in fostering sustainability-driven innovations. By unraveling the intricate tapestry of digital skills in the context of sustainable practices, this section not only contributes to the discourse on responsible technological advancements but also offers valuable insights for organizations seeking to align their innovative endeavors with environmental and societal sustainability goals.

Table 1. Compilation of strategies, digital tools, and innovation sustainability aspects found in the literature.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Digital Tools Used</th>
<th>Sustainability Aspects</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>An ecosystems approach</td>
<td>“Simpatico” software platform that improves Public Administration technological systems by simplifying the interactions of citizens and companies with public services.</td>
<td>Sustainability through citizens’ engagement.</td>
<td>[24]</td>
</tr>
<tr>
<td>Assessment method</td>
<td>3D printing technology</td>
<td>Lower energy consumption and pollutant emissions.</td>
<td>[25]</td>
</tr>
<tr>
<td>Action research</td>
<td>LAST information system service</td>
<td>Traceability and transparency of a product’s life cycle.</td>
<td>[26]</td>
</tr>
<tr>
<td>Industry–University collaboration</td>
<td>Additive manufacturing</td>
<td>More efficient and effective take-make-transmigrate approach of sustainable manufacturing.</td>
<td>[27]</td>
</tr>
<tr>
<td>Quantitative approach</td>
<td>Marketing technology acceptance model (MTAM) for digital marketing strategy and capability development</td>
<td>Sustainable digital marketing trends, enhancing capabilities, and uplifting the state of the property development sector in developing countries.</td>
<td>[28]</td>
</tr>
<tr>
<td>Capital’s Approach in Theory and Practice</td>
<td>Grausti.riga.lv online platform</td>
<td>Aims at monitoring the quality of public open spaces in Riga, Latvia.</td>
<td>[29]</td>
</tr>
<tr>
<td>Conceptual and methodological approach</td>
<td>“Pipeline” knowledge capture</td>
<td>Promotes translation of knowledge into specific cases studies in the digital built environment.</td>
<td>[30]</td>
</tr>
<tr>
<td>A Digital Earth Living Lab approach</td>
<td>Digital Earth Living Lab (DELI)</td>
<td>Sustainable digital earth (DE) tool to facilitate co-creation, validation, and testing, and thereby fostering open innovation for future generations of DE applications.</td>
<td>[31]</td>
</tr>
</tbody>
</table>
In the realm of innovation management, the utilization of digital tools emerges as an indispensable driver, particularly in the context of sustainable innovations. Examining various strategies across different domains reveals a prevailing trend wherein digitalization plays a pivotal role in fostering sustainability. For instance, the “Simpatico” software platform, as discussed by Ciasullo et al. [24], streamlines interactions within Public Administration technological systems, enhancing sustainability through increased citizen and company engagement. The incorporation of 3D printing technology in the assessment method, as explored in a study [25], not only improves efficiency but also aligns with sustainability goals by significantly reducing energy consumption and pollutant emissions.

Moreover, industry–university collaboration exemplified by the integration of additive manufacturing represents a paradigm shift toward more efficient and sustainable manufacturing practices [26]. The quantitative approach using the Marketing Technology Acceptance Model (MTAM) [28] showcases how sustainable digital marketing trends can be harnessed to uplift capabilities, particularly within the property development sector in developing countries.

While these examples underscore the pervasive influence of digital tools in sustainable innovations, it is essential to acknowledge the burgeoning sector of artificial intelligence (AI). Despite being less explored in the current context, AI holds tremendous potential for driving future sustainable innovations exponentially. Therefore, as elucidated in the Digital Sustainability Canvas as an Assessment Tool [35], it becomes imperative for educational institutions to equip students and educators with digital competencies tailored to the demands of AI-driven sustainable innovations. This forward-looking perspective ensures that the educational landscape remains at the forefront of cultivating skills essential for shaping a sustainable and innovative future. The challenges faced by educators in navigating the integration of digital tools for sustainable innovations, particularly in the context of emerging sectors like artificial intelligence, will be thoroughly examined in the upcoming section addressing RQ2.

5. Investigating RQ2

Addressing the second research question, this section aims to provide insights into the multifaceted challenges that educators encounter as they strive to equip students with the necessary digital competencies essential for future sustainable innovations. Through a systematic analysis of the existing literature and empirical evidence, this discussion will shed light on the complexities, barriers, and potential solutions surrounding the integration of digital tools in educational settings to meet the demands of rapidly evolving technological landscapes and sustainability imperatives. A study [35] suggests “Digitalization
can enhance 21st-century competencies, but faces technological challenges, teacher training, pedagogical shifts, and parental training”. Another study in Spain with a sample size of 527 teachers found that the barriers to the integration of digital technology in higher education encompass technophobia, time constraints, insufficient planning, lack of incentives, challenges in evaluation, work saturation, and the prevailing university accreditation model [36]. A reliable scientific framework outlining what it means for educators to be digitally competent is the European Framework for the Digital Competence of Educators (DigCompEdu) [37]. It offers a broad framework of reference to assist in the development of digital competencies unique to educators in Europe. “DigCompEdu” lists 22 competencies arranged into six categories: digital resources, teaching, and learning assessment, empowering learners, professional involvement, and facilitating learners’ digital competency. Technical proficiency is not the focus. The framework, on the other hand, tries to explain how digital technologies might be used to innovate and improve training and education, which is exactly the prime requirement for future pedagogy. In Table 2, the authors identified the challenges and the lessons learned from the case studies.

Table 2. Compilation of identified challenges and lessons from various case studies.

<table>
<thead>
<tr>
<th>Challenges Category</th>
<th>Identified Challenges</th>
<th>Lesson Learned</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technological challenges</td>
<td>Conflict between mastery and appropriation and between personal and educational use of technology.</td>
<td>The emphasis should shift from tool mastery to the adoption of a digital competency that includes knowledge of how technology may be used critically and reflectively in the process of creating new knowledge.</td>
<td>[38]</td>
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<tr>
<td>Lack of methods of converting traditional learning information into a relevant and usable digital format.</td>
<td>It is imperative to take these obstacles into account and minimize them when digitizing teaching and learning materials—for example, lower-resolution videos, uneven internet availability, etc.</td>
<td>[39]</td>
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<tr>
<td>AI-based tech often creates misunderstanding, misleadingness, limitations, and hidden ethical issues behind different platforms.</td>
<td>Offering instructional resources that educators can use to help K–12 students learn more about ethics and artificial intelligence.</td>
<td>[40]</td>
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<tr>
<td>Constantly changing paradigms of information and communication technologies (ICT).</td>
<td>Teachers must receive ongoing training so they may stay current on the issues and trends in education as well as the didactic opportunities provided by ICT.</td>
<td>[41]</td>
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<tr>
<td>Digital competency in appropriately using ICT has progressed from being a simple tool to a crucial educational component that necessitates training.</td>
<td>The post-COVID-19 environment has caused many significant goals, one of which is the digitization of faculty training programs and universities.</td>
<td>[42]</td>
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<tr>
<td>The conservatism of educators disconnects them from millennial learners.</td>
<td>The ability to connect problem-based learning to real-world challenges is what attracts millennials to it.</td>
<td>[43]</td>
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<tr>
<td>A pedagogical shift to a ‘simulation-based’ learning model in medical field challenges educators.</td>
<td>Educators can teach without compromising patient safety or harming them by using simulation tools for experiments.</td>
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<td>The typical level of instruction that new teachers receive throughout their training is a major element in ensuring that all teacher education instructors have the requisite abilities to adequately train pre-service teachers for</td>
<td></td>
<td>[45]</td>
<td></td>
</tr>
<tr>
<td>Lack of time</td>
<td>Inadequate Infrastructure</td>
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<tr>
<td>Regarding whether the workload required to ensure the cogent use of social media within a module is unduly resource intensive for the educator, there is evident reluctance among academics.</td>
<td>Development of national and institutional e-learning policies, improvements in IT infrastructure.</td>
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<tr>
<td>The results provide light on how technology is used and show that for educators to want to utilize digital media, there must be clarity on the educational benefit.</td>
<td>The creation of a technology infrastructure for each institution, administrators having a clear strategy for using technology, and teachers sharing their experiences using it are the most crucial components.</td>
<td></td>
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<tr>
<td>Teachers needed more time and funding to grow professionally since they had to become more adept at using digital tools and pedagogies on their own, unsupported, and in their own time.</td>
<td>For digitization to enhance and complement student-teacher and student-student relationships rather than replace them, institutions must completely rethink their learning environments.</td>
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<tr>
<td>Constructing a website with the technical training materials instructors need, and maintaining “an efficient helpdesk team to support teachers and students”.</td>
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<tr>
<td>An additional 10-week training program with teachers that uses a blended learning strategy is an extra burden.</td>
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<tr>
<td>The digital competency of teachers was effectively improved through an upskilling training session, wherein they constructed their knowledge and abilities.</td>
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<tr>
<td>Despite the limitations imposed by the pandemic lockdown, academic teachers in Norway showed various degrees of agency in adjusting to online teaching practices despite a lack of institutional support and digital competency [51]. The challenges confronting educators in the digitalization of pedagogy span various facets, from technological impediments to the ongoing need for teacher training and the necessity for a pedagogical paradigm shift. Noteworthy technological challenges include conflicts between personal and educational technology use, the absence of methods for converting traditional learning information into relevant digital formats, and the intricate nature of AI-based technologies [40].</td>
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<tr>
<td>The key lesson gleaned from these challenges underscores the imperative to shift the focus from tool mastery to embracing a broader digital competency encompassing critical and reflective use of technology in knowledge creation. Addressing the shortage of methods for transforming traditional learning information requires acknowledging and mitigating obstacles during the digitization process, ensuring equitable access to educational materials.</td>
<td></td>
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<tr>
<td>Teacher training emerges as a pivotal facet, given the ever-evolving paradigms of information and communication technologies (ICT). The literature accentuates the necessity for continuous training to keep educators abreast of educational trends and the didactic prospects offered by ICT. Moreover, the post-COVID-19 environment has accelerated the digitization of faculty training programs, accentuating the urgency of imparting digital competencies to educators in response to evolving educational landscapes [3].</td>
<td></td>
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<tr>
<td>Pedagogical shifts are imperative to bridge the disconnect between conservative teaching approaches and the preferences of millennial learners. Adopting problem-based</td>
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</table>
learning linked to real-world challenges becomes instrumental in effectively engaging millennial students. In fields like medicine, a shift to a ‘simulation-based’ learning model challenges educators but also offers a safe avenue for teaching without compromising patient safety [29].

The challenge of inadequate infrastructure, including the lack of devices and internet facilities, underscores the need for a fundamental rethink of learning environments. Institutions must develop national and institutional e-learning policies and enhance IT infrastructure to create an effective technology infrastructure.

Despite these challenges, the literature reflects the importance of upskilling educators through training programs, recognizing the additional burden this may pose. For instance, a 10-week training program with a blended learning strategy effectively improved the digital competency of teachers [50].

Looking ahead, the integration of new technologies, such as artificial intelligence, is anticipated to bring additional challenges to STEM education. Navigating these challenges will require continuous professional development, institutional support, and a commitment to fostering digital competencies among educators. As educational institutions strive to equip educators with digital competencies, they play a pivotal role in shaping the future generation of innovators, scientists, and entrepreneurs, ensuring they are adept at leveraging emerging technologies for transformative learning experiences.

6. Investigating RQ3

In the rapidly evolving landscape of education, the integration of “Arts” into STEM education, forming the holistic approach known as STEAM, emerges as a transformative strategy. This innovative paradigm not only addresses the conventional challenges faced by educators in upskilling their digital competencies but also aligns seamlessly with the evolving needs of the new generation of innovators. As the contemporary world demands interdisciplinary skills to navigate complex challenges, the inclusion of Arts in STEM education proves pivotal.

The challenges encountered by educators in the digital age, marked by constant technological evolution, necessitate a creative and adaptive approach to professional development. The conventional barriers to upskilling, such as time constraints and technophobia, can be mitigated through the integrative and experiential nature of STEAM education. Arts, with an emphasis on creativity, critical thinking, and expression, serve as a catalyst for educators seeking to enhance their digital competencies. By incorporating artistic elements into STEM pedagogy, educators are encouraged to explore innovative teaching methods, fostering a dynamic learning environment. The Directorate of Primary Education has initiated a European program under Eras in Arts. This program focuses on the multifaceted personalities of today’s children and future adults, who need to have developed skills, flexibility, critical thinking, and diverse personalities. “STEAM &digital skills: looking for the Leonar dos of Tomorrow” (see https://www.steamedu-project.eu/index.php (accessed on 5 December 2023) is the name of the program, which aims to provide instructors interested in studying STEAM with an integrated distance learning platform and a framework for STEAM methodology. Different frameworks have recently come into the picture, such as Computational Science in Education, which integrates computational modeling into inquiry-based teaching, aligning with Computational Thinking. The ‘Computational STEAM Content Pedagogy’ (CPACK) model by Psycharis et al. [15] links STEAM’s content-rich principles with computational methodologies. CPACK encourages iterative computational experiments, fostering digital competencies and interdisciplinary problem-solving.

Table 3 presents an array of tools and pedagogical strategies aimed at enhancing educators’ proficiency in STEM pedagogy. In the realm of visualization and spatial designing, GeoGebra (Version 6) takes precedence, guiding educators through a Design-Based Research (DBR) approach and fostering iterative design experiences to refine spatial design and visualization skills [51]. Szilágyi et al. [52] built a card game called LimStorm (a
two-year trial program) to practice the crucial limits of real number sequences for groups of four to ten students, capitalizing on the benefits of game-based learning. Transitioning to the realm of digital art, the “Digital Stories” curriculum emerges, emphasizing animated narratives within a digital art-centered STEAM framework, where creativity and narrative adeptness intertwine [53].

In the sphere of design thinking, the fusion of Design Fabrication and FabLab with a Community of Practice approach beckons educators into collaborative design thinking, creating an environment of shared expertise [54]. Creative thinking and student innovation find their haven in the Virtual Classroom Learning Environment (VCLE), introducing online gamification mechanisms to kindle creative thinking and innovation among students [55].

Creative coding, exemplified by E-Textile Design, becomes a canvas for artistic envisioning, seamlessly intertwining creativity and coding skills [56]. The domain of music learning witnesses the convergence of Chrome Music Lab, Scratch Music, and other applications in a digital-based STEAM initiative for music education, showcasing the fusion of creativity and technological prowess [57].

Venturing into game development, a quantitative analysis of virtual reality applications underlines the integration of emerging technologies into pedagogy [58]. Digital literacy, navigated through distance learning tools such as Moodle and Google Classroom, spearheads the training of specialists for the digital economy, underlining the significance of digital literacy in educational landscapes [59].

In the realm of computational thinking, RoboSTEAM, centered on robotics and physical devices, champions a Challenge-Based Learning Approach, seamlessly infusing computational thinking into STEM pedagogy [60].

Table 3. Identification of digital platforms in pedagogy for upskilling.

<table>
<thead>
<tr>
<th>Upskill</th>
<th>Digital Platform Used</th>
<th>Pedagogy Approach</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visualization and spatial designing</td>
<td>GeoGebra (Version 6) “Digital Stories” offered a curriculum for group creation of meaningful animated digital stories on women’s and girls’ experiences leading in the business and educational environments.</td>
<td>Design-based research (DBR)</td>
<td>[52]</td>
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<td>Digital art</td>
<td>Design Fabrication and Fab-Lab</td>
<td>A digital art-centered STEAM curriculum</td>
<td>[53]</td>
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<tr>
<td>Design thinking</td>
<td>Design Fabrication and Fab-Lab</td>
<td>Community of Practice</td>
<td>[54]</td>
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<td>Creative thinking and student innovation</td>
<td>Virtual classroom learning environment (VCLE)</td>
<td>Online ‘gamification’ mechanisms</td>
<td>[55]</td>
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<tr>
<td>Creative coding</td>
<td>E-TEXTILE DESIGN Chrome Music Lab, Scratch Music, Groove Pizza, earSketch, UPISketch and iMuSciCA applications.</td>
<td>Artistic envisioning</td>
<td>[56]</td>
</tr>
<tr>
<td>Music learning</td>
<td></td>
<td>Digital-based STEAM applications</td>
<td>[57]</td>
</tr>
<tr>
<td>Game development</td>
<td>virtual reality applications</td>
<td>Quantitative analysis of data on virtual reality applications available on the market</td>
<td>[58]</td>
</tr>
<tr>
<td>Digital literacy</td>
<td>Distance learning tools such as Moodle, Google Classroom, and Microsoft Teams</td>
<td>Training specialists for the digital economy [59]</td>
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<tr>
<td>Computational thinking</td>
<td>RoboSTEAM (Robotics and Physical Devices)</td>
<td>Challenge-based learning approach [60]</td>
<td></td>
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<tr>
<td>Spatial thinking</td>
<td>GIS Stories</td>
<td>Public participation geographic information systems (PPGIS) via public engagement [61]</td>
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<tr>
<td>Data analysis</td>
<td>Common Online Data Analysis Platform (CODAP)</td>
<td>Building interactive multimedia stories that integrate data analysis and visualization [62]</td>
<td></td>
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<tr>
<td>Creative thinking</td>
<td>micro:bit</td>
<td>STEAM curriculum for students with disabilities [63]</td>
<td></td>
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<tr>
<td>Co-creation Sustainability and co-creation</td>
<td>BODYSOUND</td>
<td>Patient innovation [64]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Digital fabrication laboratories</td>
<td>Design workshop with multidisciplinary team [65]</td>
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This diverse tapestry underscores the experimental nature of contemporary STEAM-based models, signaling the need for a more robust pedagogical framework. As educators embrace various STEAM approaches and digital tools, the trajectory emerges—a journey poised to prepare students for the dynamic challenges of the digital age, nurturing innovation and critical thinking in tandem.

Culturally responsive education frameworks, like the Culturally Responsive-Sustaining (CR-S) Education Framework, are intended to establish student-centered learning settings that support positive academic outcomes, validate cultural identities, and enable students to act as change agents in the community [66]. These frameworks acknowledge variety as a resource for teaching and learning and are based on a cultural perspective on human development and learning [67]. The cultural and linguistic identities, experiences, and modes of knowing of different students, families, and communities have to be prioritized and maintained. The following are the four guiding concepts form the foundation of the CR-S framework: inclusive curriculum and assessment, high standards and demanding instruction, a positive and encouraging environment, and continual professional development. For future STEAM students’ digital competencies to foster sustainable innovations, the integration of a Culturally Sustaining Education Framework (CSEF) within the pedagogy is inevitable. The authors propose a novel framework, as shown in Figure 4, that not only amalgamates (STEAM) but also upholds and leverages the cultural identities and practices of students. Its overarching aim is to enhance digital literacy and innovation skills while promoting cultural diversity and sustainability. A structured approach to crafting such a framework delineates key logical components that underpin both cultural sustainability and digital innovation.
Figure 4. Proposed Culturally Sustaining Education Framework (CSEF) for STEAM.

- Cultural Identity Affirmation: Recognizing and appreciating the varied cultural origins of the students is essential to this component. Cultural histories, values, narratives, and practices must be incorporated into STEAM curricula. A few strategies could be incorporating scientific ideas with traditional knowledge systems, using case studies and examples that are relevant to the culture in question, and encouraging STEAM subject exploration from a variety of cultural viewpoints.
- Inclusive Pedagogy: Teaching methods that take into account students’ varied needs—which include a range of learning preferences, language skills, and cultural backgrounds—are guaranteed to be inclusive pedagogies. A key component of this strategy is engagement, along with flexibility and accessibility.
- Digital Literacy and Competency: This component concentrates on giving students 21st century digital competencies, which include communication, teamwork, creativity, and critical thinking within a STEAM framework through the identified digital tools as mentioned in Table 3.
- Sustainable Innovation: Creating solutions that are both culturally aware and environmentally sustainable is what is meant to be understood as sustainable innovation under the novel CSEF framework. It is recommended that students use their digital skills and STEAM knowledge to address global issues while honoring cultural customs.
- Continuous Reflection and Adaptation: This component ensures the ongoing relevance and efficacy of the framework amidst evolving cultural and technological landscapes. It necessitates regular assessment and reflection to refine curriculum content, teaching methods, and learning outcomes.

The goal of the CSEF for STEAM is to equip students to be creative leaders in a world that is both culturally varied and digitally connected. This framework aims to enable students to contribute to sustainable innovations that respect and benefit their communities and the global society by employing inclusive pedagogies, fostering sustainable innovation, enhancing digital literacy, and committing to ongoing reflection and adaptation. This method ensures that STEAM education is fair, current, and progressive, enabling it to tackle the intricate problems of the twenty-first century.
7. NOISE Analysis

This section describes the synergistic relationship between Arts and STEM within the STEAM paradigm, emphasizing how it not only addresses the challenges faced by educators in digital upskilling but also prepares the next generation of innovators to tackle the complexities of modern world sustainability. A few less common but no less noteworthy STEAM concerns were those involving technological integration and assessment-related problems [68]. Previously, discipline topic knowledge was examined through teaching and research using a SWOT analysis of STEM education in academia [69]. Similarly, through the alternate NOISE analysis of the transformative potential of STEAM, this argument aims to stimulate intellectual curiosity and prompt further investigation into the intersection of arts, digital competencies, and sustainable innovation in education. The NOISE analysis model serves as a comprehensive framework for understanding the intricacies of upskilling educators in digital competence, providing a structured approach to address the evolving landscape of pedagogy.

In the context of our study, the NOISE model, as shown in Figure 5, plays a pivotal role in shaping a robust framework for future pedagogy through STEAM models. The identified Needs (N) involve constructing a framework covering the development of all 22 designated digital skills for innovation. This aligns with the study’s overarching goal of assessing the various facets of digital competence and proposing a comprehensive framework that embraces the dynamic nature of technological advancements.

![NOISE Analysis Diagram](image)

**Figure 5.** Pictorial representation of the NOISE analysis results.

Opportunities (O) identified through the NOISE analysis emphasize continuous upskilling of educators, ICT training, ensuring adequate infrastructure, allowing time for educators to adapt to pedagogical shifts, providing clarity in instructions, and sustainably promoting innovation. The literature survey reinforces these opportunities by shedding light on the potential of STEAM-based models, digital tools, and effective training programs to empower educators in the digital era.

The Improvements (I) aspect suggests that universities need to hire tech experts to equip educators with digital tools, introduce gamification in courses, and adopt STEAM-
based curricula. This aligns with the findings from the literature survey, which emphasizes the importance of incorporating novel pedagogical approaches, including STEAM, to enhance digital competence among educators.

Strengths (S) identified in the NOISE analysis include the novelty in pedagogy for digital competence. The literature survey corroborates this strength by showcasing the potential of STEAM-based models and digital tools in transforming traditional teaching methods, fostering innovation, and equipping educators with the necessary digital competencies.

Overall, the NOISE analysis model, when applied to the context of upskilling educators in digital competence through STEAM models, provides a structured and strategic approach. The alignment of the NOISE model components with the findings from the literature survey underscores the significance of this study in shaping the future of pedagogy, emphasizing the integration of digital skills, STEAM models, and innovative teaching methods in educational institutions.

8. Limitations

While this study has made some contributions to understanding the role of STEAM models in upskilling educators’ digital competence, it is essential to acknowledge certain limitations that may impact the comprehensive outlook of the utility of STEAM in future pedagogy. Firstly, the literature data collection was confined to the period of 2013–2023, potentially excluding earlier seminal contributions. Although this timeframe was chosen to capture recent developments, it might have omitted foundational works that paved the way for current perspectives on digital competence in education.

Moreover, this study primarily relied on Scopus and Web of Science (WoS) sources for paper selection. While these databases are reputable, there could be valuable contributions outside these platforms that were not considered. To address this, efforts were made to include significant works even if they were not part of Scopus or WoS, ensuring a more comprehensive analysis. The focus on “digital competence” as the primary keyword for the literature review may introduce a limitation. There could be other essential skills crucial for teaching innovation that were not explicitly covered. Addressing these mentioned boundaries, future research may explore a broader range of skills to provide a more holistic understanding of the competencies needed for effective pedagogy in the digital age.

Potential biases may exist in the selection of studies and the design of the framework. The exclusion of certain papers or the emphasis on specific keywords could introduce bias. However, the NOISE analysis applied to the study helps in addressing these biases by providing a structured framework for needs assessment, opportunity identification, improvement strategies, and leveraging strengths.

9. Conclusions

In summary, this paper embarked on a comprehensive exploration of the intersection between STEAM education, digital competence, and sustainable innovations, aiming to unravel the mechanisms through which educators can be upskilled to navigate the challenges of a rapidly evolving educational landscape. A significant number of institutions have chosen an online platform since the pandemic. The effectiveness of STEAM can be thoroughly examined from the perspectives of students, instructors, and administrative staff by utilizing the pedagogical frameworks Community of Inquiry (COI), particularly for Art-based pedagogies [70]. This allows for an understanding of their experiences and how they have adjusted to the move to an online environment. The primary results of the literature review underscore the multifaceted nature of digital competence, emphasizing its significance in the knowledge society, especially highlighted by the challenges posed by the recent pandemic. Sustainable innovation, with its ecological, economic, and social dimensions, emerged as a complex yet crucial concept, demanding a holistic and inclusive approach.
Key takeaway lessons from the literature include the pivotal role of digital competence in addressing the digital divide, the necessity for continuous upskilling of educators, and the potential of STEAM pedagogy in fostering a transdisciplinary and holistic educational approach. The NOISE analysis provided a structured lens through which to view the needs, opportunities, improvements, and strengths in implementing STEAM-based pedagogy for digital upskilling. The holistic significance of STEAM in building future innovators of future lies in its capacity to equip educators with the digital competencies needed to prepare students for the challenges of the modern world with proper digital resources. By integrating science, technology, engineering, arts, and mathematics, STEAM offers a comprehensive framework that aligns with the 21st century competencies advocated by the European Commission.

Practically, this study suggests that universities and educational institutions should invest in continuous training, hiring tech experts, and adopting STEAM-based curricula to enhance the digital competence of educators. The NOISE analysis serves as a practical guide for institutions to identify and address the needs, seize opportunities, implement improvements, and leverage strengths in the digital upskilling process.

Contributing to the existing body of research, this paper sheds light on the symbiotic relationship between STEAM pedagogy, digital competence, and sustainable innovations, providing a nuanced understanding of their interconnectedness through the CSE framework. This framework is designed to be flexible and adaptable, allowing for implementation in diverse educational contexts. It encourages educators to critically engage with both the content and the pedagogical approaches they use, ensuring that they are responsive to the needs of their students and the demands of a rapidly changing world. Moving forward, future research directions involve building a robust conceptual framework for STEAM-based pedagogy, delving deeper into the specific components that contribute to effective digital upskilling, and exploring innovative approaches to address emerging challenges, including the integration of artificial intelligence in education. As an expert in pedagogy, the journey of upskilling educators in the digital age is an ongoing endeavor, and this study marks a potential stride toward comprehending and navigating this transformative landscape.

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