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A Systematic Review: Digital Learning in STEM Education

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ABSTRACT

The fourth industrial revolution's transformative trajectory of education highlights the critical role of Science, Technology, Engineering, and Mathematics (STEM), a meta-discipline characterized by active, problem-centric approaches like game-based learning, which is critical in navigating the transformations induced by the convergence of advanced technologies. However, the integration of Information and Communication Technology (ICT) has encountered substantial challenges in developing countries, with debates surrounding its potential to diminish hands-on learning experiences and pragmatic engagement in educational settings. Given the growing significance of digital educational content, this study undertakes a systematic review to examine the usefulness and implementation of digital learning in STEM education. The primary issue being researched is determining digital interventions' best integration and impact in improving STEM learning experiences and results. A thorough examination of various research, concentrating on various educational levels and digital technologies, was carried out to get significant insights into their pedagogical implications and efficacy. This paper employs the PRISMA approach to collect primary data using keywords such as "digital learning," "technology learning," and "STEM education." An advanced search on SCOPUS and Web of Science yielded 27 articles, revealing three central themes: (1) digital integration and innovation in STEM Education, (2) barriers, perceptions, and motivation in STEM learning, and (3) interdisciplinary and cross-cultural approaches in STEM education. The anticipated findings will provide a more nuanced understanding of digital learning's multifaceted effects on student engagement, academic performance, and interest in STEM subjects and highlight the transformative potential of digital tools in fostering innovative and inclusive learning environments. Finally, this study aims to provide significant insights into the techniques for effective integration of digital technologies in STEM, enhancing learning experiences and supporting the development of critical 21st-century skills and competencies.

1. Introduction

Incorporating technology into education has brought about a significant transformation in traditional teaching methods, offering novel prospects for engaging students and enriching their learning experiences. Notably, integrating digital learning in Science, Technology, Engineering, and Mathematics (STEM) education has garnered considerable attention recently. This paper aims to

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conduct a systematic review to assess the current state of digital learning in STEM education, examining its impact on student outcomes, the challenges, and opportunities it presents, and the implications for future research and practice. STEM education is crucial in cultivating critical thinking, problem-solving skills, and technological literacy [1-4], all of which are essential for individuals to thrive in the digital age. Nonetheless, conventional teaching methods often encounter difficulties in effectively captivating students and fostering a profound comprehension of complex STEM concepts [5-8]. Digital learning, encompassing a wide array of technology-based tools and resources, provides alternative approaches to teaching and learning that can address these challenges.

The utilization of digital learning in STEM education has demonstrated multiple advantages. Firstly, it offers interactive and immersive experiences that can enhance students' engagement and motivation [9,10]. Through digital simulations, virtual laboratories, and interactive multimedia resources, students can explore scientific phenomena and engineering principles in a hands-on, experiential manner, leading to a deeper understanding of STEM concepts and an increased interest in pursuing STEM-related fields. Secondly, digital learning provides opportunities for personalized and adaptive instruction [11]. Intelligent tutoring systems and learning analytics allow educators to tailor instruction to meet individual students' needs and provide targeted feedback. This individualized approach promotes self-paced learning and accommodates diverse learning styles, facilitating better knowledge retention and higher academic achievement. Additionally, digital learning facilitates collaborative and social learning experiences [12,13]. Online platforms, discussion forums, and video conferencing tools enable students to collaborate with peers, mentors, and experts worldwide. This fosters the development of teamwork, communication, and problem-solving skills, which are crucial for success in STEM fields and the modern workforce.

However, despite the numerous benefits of digital learning in STEM education, there are also challenges that need to be addressed [14,15]. The digital divide, characterized by unequal access to technology and internet connectivity, remains a significant barrier to equitable participation in digital learning initiatives [16]. Furthermore, effective technology integration into STEM classrooms requires teachers to possess adequate technological skills and pedagogical knowledge. Therefore, professional development and ongoing support are crucial to ensure educators can effectively leverage digital tools and resources to enhance student learning [17,18]**.** In conclusion, digital learning holds immense potential to revolutionize STEM education by providing interactive, personalized, and collaborative learning experiences. This systematic review will critically analyze the existing research literature on digital learning in STEM education. It will scrutinize its impact on student outcomes, its challenges and opportunities, and the implications for future research and practice. By synthesizing the available evidence, this review aims to inform educators, policymakers, and researchers about the best practices for integrating digital learning in STEM education, ultimately contributing to the advancement of STEM teaching, and learning in the digital era.

2. Literature Review

This literature review explores the integration of digital learning in STEM education, focusing on its impact, methodologies, and challenges. The review aims to offer a comprehensive resource for educators and researchers to optimize educational experiences in the 21st century. The study by Nurulaini Jaafar *et al*., [19] underscores the pivotal role of technology in education, where tools like Geogebra, Desmos, Symbolab, and WolframAlpha enhance learning by enabling students to visualize and process problem-solving steps easily, thus making learning more engaging, efficient, and effective. Additionally, according to Fatma Al-Duhani *et al*., [20] the use of virtual laboratories is highlighted for their significant contribution to students' understanding of science, as they facilitate

active participation in experiments, provide instant feedback, and allow interaction with otherwise abstract scientific phenomena, such as electron movement. The integration of virtual labs into educational curricula is strongly recommended for their dynamic, interactive capabilities that improve the comprehension of complex scientific concepts beyond what direct observation alone can offer.

In 2023, Gui *et al.,* [21] published a paper investigating the effectiveness of digital game-based STEM education and the impact of additional game-design aspects. Two meta-analyses showed a medium to large general effect of digital game-based STEM learning over traditional learning. The effectiveness varied depending on the subject, game style, and learning outcome. Adding game design components had a minor to medium enhancing effect, with content learning components being more successful than gaming fun [21]. A research finding by Gomez *et al.,* [22] also points towards game-based assessment (GBA) studies focusing on K-16 education. The study found that GBAs positively affect assessment, particularly in STEM content, cognitive skills, and soft skills. However, limitations suggest future research could benefit from larger data samples and specialized algorithms. The review also discusses current trends, challenges, and recommendations for future research in the GBA field.

Both Lee *et al.,* [23] and Vandenberg *et al.,* [24] investigate new instructional practises from distinct perspectives. Lee *et al.,* [23] investigate the use of game-based learning to elevate STEM education, utilising platforms such as Scratch and Code.org to teach programming principles through visual, game-like experiences, with the goal of stimulating the attention of non-STEM students by making learning entertaining and interactive. Vandenberg *et al.,* [24], on the other hand, focus on AI literacy among middle school pupils, particularly in underserved rural areas. They're creating an AI-centric environment that's integrated with game creation activities, with the goal of sparking passion and expertise in computer science. Both studies highlight the value of interactive, game-based techniques in increasing educational engagement and learning in computer science and STEM. Still, they do so in distinct contexts, at various educational levels, and in different demographic settings.

Apart from game-based learning, the study of Flegr *et al.,* [25] found that combining virtual and video experiments seemed more effective than hands-on experimentation in STEM education. Due to the Covid-19 pandemic, digital technologies have enabled online experiments. The use of digital technologies is a transformative strategy with enormous potential for the field of STEM education. It is poised to revolutionise experimental learning and enhance scientific education in the twenty-first century by making it more approachable, interesting, inclusive, and efficient. In addition, Sidekerskienė and Damaševičius [26] research from 2023 looks into how well digital escape rooms work in STEAM (Science, Technology, Engineering, Arts, and Mathematics) education, with a focus on how they affect student engagement and learning, especially in maths. They suggest a conceptual framework that explains the design process in detail and gives examples of common design patterns for escape rooms. The thorough analysis suggests that using digital escape rooms as a teaching tool is a dynamic and inclusive way to create a rich and immersive learning environment where students feel more engaged and included, which could lead to better learning results.

In a different study, Brändle *et al.,* [27] discuss that teacher training institutions often struggle with using digital media effectively and don't understand the benefits of using digital ideas in the classroom. The research focuses on STEM, the language literature arts (LLA), and social sciences (SOCS) subject groups and examines their skills, motivations, and attitudes toward digital media use. STEM teachers are more competent in technological, content, and pedagogical knowledge, but their motivations remain consistent. The study suggests promoting technological skills and positive attitudes to boost motivation. Meanwhile, a study from Kibirige [28] explores the challenges faced by primary school teachers in Uganda in integrating Information and Communication Technology

(ICT) into STEM subjects. Key barriers include limited computer access, inadequate internet connectivity, and lack of ICT textbooks. Addressing these requires increased infrastructure investment, teacher training, and curriculum development. By addressing these issues, policymakers can help narrow the digital divide in Uganda and other developing countries.

3. Material and Methods

3.1 Identification

The procedure of selecting relevant papers for this study involves three primary phases (identification, screening, and eligibility) in the systematic review process. The initial stage involves the identification of keywords and the search for associated terms through the utilization of resources such as the thesaurus, dictionaries, encyclopaedias, and prior research. Subsequently, once the pertinent keywords had been determined, search strings were generated on Scopus and Web of Science databases (see Table 1). The current study project successfully obtained 1660 papers from both databases during the first stage of the systematic review process.

Table 1
The search string

Scopus	TITLE-ABS-KEY (digital AND learning AND stem AND education) AND (LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2023)) AND (LIMIT-TO DOCTYPE, "ar")) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (PUBSTAGE, "final")) Access Date: 23 September 2023
WOS	digital AND learning AND stem AND education (Topic) and 2023 or 2022 (Publication Years) and Article (Document Types) and English (Languages) Access Date: 23 September 2023

3.2 Screening

During the first phase of the investigation, 1415 papers were excluded based on the researchers' varied inclusion and exclusion criteria (see Table 2). Research papers were the primary emphasis and were chosen using the first selection criterion. In addition, systematic reviews, reviews, meta-syntheses, meta-analyses, monographs, book series, chapters, and conference proceedings were excluded from the most recent studies during this phase. Furthermore, the scope of the review was limited to English-language publications. It is critical to emphasize that this study was limited to two years (2022-2023). Following the application of the predetermined criteria, a total of 245 articles were distilled. In the second phase, 56 articles were identified as duplicates and methodically removed from the amassed assortment of selected articles.

Table 2
The selection criterion is searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2022 – 2023	< 2022
Literature type	Journal (Article)	Conference, Book, Review
Publication Stage	Final	In Press

3.3 Eligibility

A total of 189 articles have been prepared for the third level, which is known as eligibility. At this point, all article titles and important content were thoroughly assessed to ensure that the inclusion standards were met and that the papers fit the current study with the current research aims. As a result, 162 reports were excluded owing to being out of the field, having a title that was not statistically linked to the study's objective, and having an abstract that was not significantly related to the study's purpose. Finally, 27 articles (see Figure 1) are accessible for review.

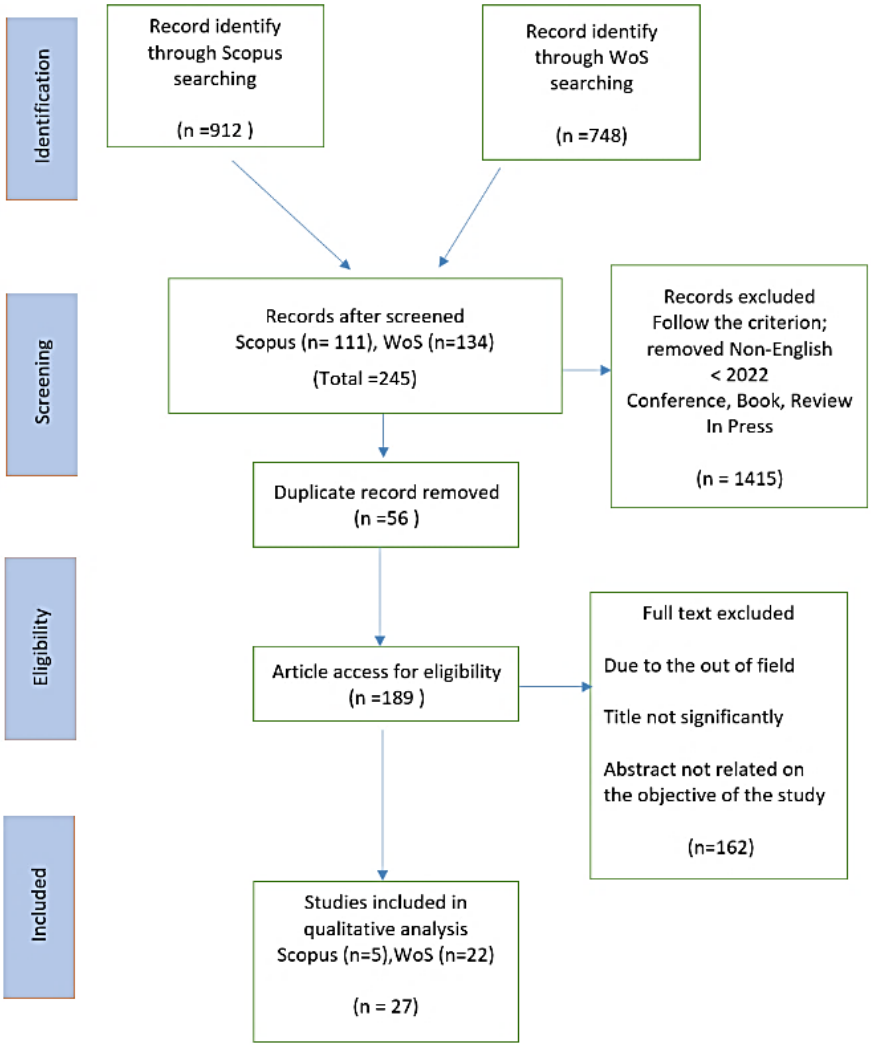


Fig. 1. Flow diagram of the proposed search study [27]

3.4 Data Abstraction and Analysis

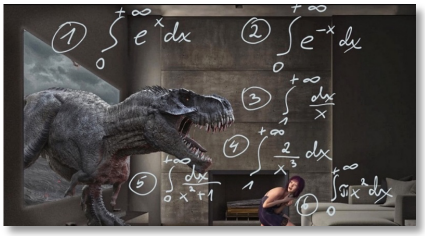
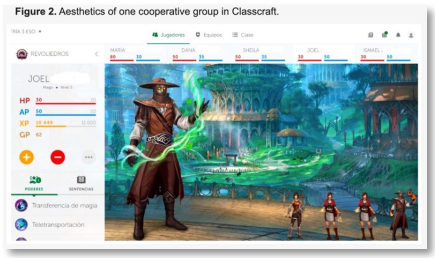
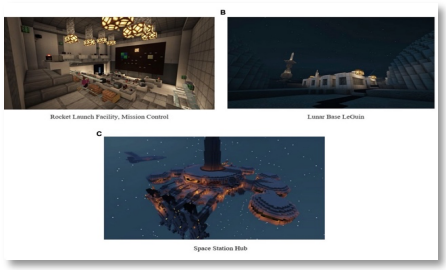
One of the assessment procedures employed in this study was integrative analysis, which was used to investigate and synthesize a variety of research designs (quantitative, qualitative, and mixed methods). The competence study's purpose was to find relevant subjects and subtopics. The data collection stage was the first step in the theme's development. Figure 1 depicts how the authors methodically examined 41 articles for assertions or material pertinent to the current study's issues. The authors then assessed the most recent significant studies on digital learning in STEM education. All studies' methodologies, as well as the research findings, are being investigated. Following that,

the author worked with other co-authors to identify themes based on the findings in the context of this study. A log was kept throughout the data analysis process to capture any analyses, points of view, puzzles, or other thoughts pertinent to the data interpretation. Finally, the writers compared the data to check if the theme design process was inconsistent. It is worth mentioning that if there are any disputes between the notions, the authors discuss them. The motifs that were created were eventually altered to guarantee consistency. The assessments were carried out by two specialists, one specializing in technology education and the other in STEM education, to ensure the authenticity of the challenges. By establishing domain validity, the expert review step helps ensure each sub-theme's clarity, significance, and sufficiency. Adjustments have been made at the author's discretion based on expert feedback and opinions.

4. Result and Finding

Based on the study's findings, several examples of digital use in STEM education can potentially be employed, depending on appropriateness (refer to Table 3).

Table 3
Examples of digital use in STEM education

Example images	Sources of digital use in STEM education
	**Source:** *Out-of-the-Box Learning: Digital Escape Rooms as a Metaphor for Breaking Down Barriers in STEM Education* [24]. Danger Room: The university students should solve an improper integral with one infinite bound and choose converging integrals. The key is the convergent integrals' numbers in increasing order. Numbers ①–⑥ denote the answer options.
 a) Fourth grade (b) Fifth grade (c) Sixth grade	**Source:** *Robotics Education in STEM Units: Breaking Down Barriers in Rural Multigrade Schools* [28] The students determined the path traveled by their robot with different loads on the same surface and a surface with different roughness levels.
 **Figure 2.** Aesthetics of one cooperative group in Classcraft.	**Source:** *Geometry with a STEM and Gamification Approach: A Didactic Experience in Secondary Education* [29] Students can award points (HP, AP, XP, and GP): health points (HP) are given for well-done activities; students use ability points (AP) to activate powers; experience points (XP) are extra points for good behavior and gold pieces (GP) are badges that could be transformed into powers that students could use in class or to obtain virtual object or mascots.
 Rocket Launch Facility, Mission Control Lunar Base LeGuin Space Station Hub	**Source:** *Using Minecraft to cultivate student interest in STEM* [30] Teachers can utilize a set of Minecraft worlds as supplementary activities in STEM teaching. It includes a Rocket Launch Facility, the Lunar Base LeGuin, and a Space Station.

Based on the search technique, 27 articles were extracted and analyzed. All articles were categorized based on three main themes, which are (1) digital integration and innovation in STEM Education (12 articles), (2) barriers, perceptions, and motivation in STEM learning (9 articles), and (3) interdisciplinary and cross-cultural approaches in STEM education (6 articles) (Table 4).

Table 4
The research article's findings are based on the proposed search criterion.

Theme 1: Digital Integration and Innovation in STEM Education		
Title	Methodology	Results
Out-of-the-Box Learning: Digital Escape Rooms as a Metaphor for Breaking Down Barriers in STEM Education [26]	• Purpose: To explore the application of digital escape rooms as an innovative practice in STEAM education in Europe • Study type: Qualitative (Case Study) • Innovative tools: Digital escape rooms (six escape room design patterns) • Participants: 21 students from the Kaunas University of Technology	• Digital escape rooms are an immersive and interesting way to teach STEAM subjects like critical thought, problem-solving, and teamwork. • Initial research showed that well-made digital escape rooms could make STEM learning more fun, interesting, and useful for everyone. • They have the potential to change how people think about STEM topics, which are often seen as hard and scary and can encourage active and hands-on learning.
Student Self-perception on Digital Literacy in STEM Blended Learning Environments [33]	• Purpose: To determine how students' perceived levels of digital literacy affect their navigation of Learning Management Systems (LMS) and overall academic performance when they enter tertiary blended learning environments in STEM degrees. • Study type: Quantitative. • Data collection: Questionnaires (level of digital literacy) • Respondents: 282 students migrating into tertiary blended learning environments in STEM degrees	• The study demonstrates a delicate balance between students perceived digital competence, enthusiasm to participate in online learning settings, and academic success. • In all STEM courses, high-achieving students use LMS resources more frequently than mid- or low-achieving students. On the other hand, students with high perceived digital literacy do not regularly do better overall. • Due to enhanced LMS involvement, students with low perceived digital literacy do better in certain online assessment assignments. • This emphasizes the importance of a balanced approach to harnessing digital literacy for academic performance in blended learning situations.
Digital creativity in STEM education: the impact of digital tools and pedagogical learning models on the students' creative thinking skills development [34]	• Purpose: Impact of digital creativity learning practices on the development of students' creative thinking, with a focus on fluency, flexibility, originality, detailing, and metaphoricity. • Study type: Quantitative • Respondent: 60 (9th grade Chinese students)	• The digital environment was discovered to be supportive of pupils' creative expressions. • The usage of digital technologies and novel learning methods was discovered to boost students' creative thinking skills considerably. • Compared to the control group, students in the experimental group exposed to digital creative learning practices performed better on creativity-related markers.
Playable Experiences	• Purpose: To develop and describe a model for teaching students at the tertiary level	• The concept is practical and relevant in the development of digital solutions such as

Through Technologies: Opportunities and Challenges For Teaching Simulation Learning And Extended Reality Solution Creation [35]	Simulation Learning and Extended Reality (XR) skills applicable in various higher education contexts. • Study type: Mixed-mode (project-based approach) • Focus: Practice-based learning and technology	Simulation Learning and XR, which is especially useful for pre-service teachers in technology (STEM). • It is adaptable and can be used in various educational and geographical settings. • Technology's impact on learning and social well-being requires balancing positive effects against distractions, addressing potential negatives like cyberbullying, and promoting social cohesion through real-world connection and conflict resolution.
Using Minecraft to cultivate student interest in STEM [32]	• Study type: Quantitative and qualitative methods to assess the impact of the What-If Hypothetical Implementations in Minecraft (WHIMC) project on Filipino students' interest in STEM. • Quantitative analysis: Pre- and post-STEM Interest Questionnaire (SIQ) and Game Experience Questionnaire (GEQ) • Qualitative analysis: Open-ended questions	• Analysis showed that post-WHIMC modules did not affect students' STEM interests, but the Choice Actions construct showed that students realized STEM occupations need work. • The GEQ was similar for high- and low-performers, but high-performers scored higher in Immersion. • High performers usually have more pleasant, interesting, and fun learning experiences. • Students do better on tests outside of games when they understand everything about a lesson. • Even for high-performers, open-ended learning settings with tasks requiring exploration, observation, and higher-order thinking can be hard.
STEM Teacher Digital Literacy: Relationship Between Digital Literacy And Technology Integration In Teaching And Learning Post Covid-19 [36]	• Purpose: To investigate STEM instructors' digital literacy and technology integration abilities. • Methodology: 150 Kuala Terengganu STEM instructors - simple and stratified random selection method • Data collection: A structured questionnaire Data Analysis: Correlation and linear regression	• STEM instructors were discovered to have a relatively high degree of digital literacy following COVID-19. • Correlation Between Digital Literacy and Technology Integration: A link was identified between STEM educators' digital literacy and their ability to incorporate technology. • It is estimated that STEM educators' digital literacy skills influence 47% of technology incorporation.
First experiences of integrating computational thinking (CT) into a blended learning in-service training program for STEM teachers [37]	• Purpose: Redesign an in-service teacher training program into a blended learning format, incorporating both online and in-person phases. • Study type: Quantitative. Online survey with a pre-, post-, and follow-up questionnaire • Participants: 104 in-service science teachers at secondary-level schools in Germany	• Two-thirds of teachers were unfamiliar with CT at the outset, but interest in the subject was high. • The program successfully raised awareness about the significance and meaning of CT. • It was observed that teachers who engaged with CT during the intervention implemented more CT-related classroom practices afterwards.
The Usefulness of Digital Serious Games in Engineering for	• Purpose: To examine the perspectives regarding an educational game's utility. • Study type: Mixed-method exploratory research design.	• Students have different expectations for educational digital games vs. leisure games utilized outside the classroom. • Few students (14/26 for examinations and

Diverse Undergraduate Students [38]	• Participants: 201 students. • Focus: How intuitive the students perceived the educational game to be.	19/26 for interviews) thought the educational game was effective for exam preparation. • Games that included significant course content and mathematical calculations, particularly those connected with STEM courses, were scored higher.
Covid-19 Effect on the Assessment of the Use of Smartphone Apps in STEM Learning [39]	• Purpose: To determine how the altered learning environment caused by COVID-19 affected the evaluation of mobile applications for learning STEM subjects at two universities. • Study type: Quantitative (survey) • Participants: 38 teachers (ages 32-52) and 188 students (ages 19-21) • Three primary STEM learning apps and nine supplementary apps were analyzed to determine their benefits and drawbacks.	• Findings revealed that these apps provide expanded opportunities for students, availability in the Russian language, and functionality such as appointment scheduling. • Due to adolescents' rising usage of mobile devices, important considerations include the time period for completing classes and the desire to complete tasks. • The evaluation of such learning aids should consider the ability to execute work outside of the digital domain, screen time reduction, and user accessibility. • The assessment emphasized that mobile application-based learning should promote critical thinking, a drive to succeed, and participation in project activity.
SmaEPho–Smart Photometry in Education 4.0 [40]	• Purpose: To present and evaluate an intelligent photometric measurement system, SmaEPho, integrated with a digital counterpart to improve STEM education. • The SmaEPho system is a photometric measurement device that uses intelligent sensor technology to generate data on user behavior.	• SmaEPho provides sufficient deviation accuracy for experimental applications in schools and outstanding usability. • It combines intelligent digital twins with SmaEPho to improve methodological and didactic approaches to teaching. • The method permits identifying cognitive processing, which could be critical in educational studies. • The findings pave the way for future data analytics and machine learning systems.
LabPi: A Digital Measuring Station for STEM Education 4.0 [41]	• Purpose: LabPi is designed to be a low-cost, accurate, and easy-to-use way to improve science education, research, and teaching by using digitalization to make teaching and learning processes more efficient. • Study type: Quantitative (survey) • Respondent: 193 teachers and students. • It combines a minicomputer and powerful sensors, allowing numerous measured values to be recorded individually or combined.	• LabPi is a modular, cost-effective solution for chemistry education that provides precise and user-friendly measurements. • It seeks to optimize teaching-learning processes by addressing errors and operational complexity in traditional devices. • LabPi's digitization improves science education, research, and instruction, making it an excellent option for students and educators.
Algorithmic thinking development through physical computing activities with Arduino in STEM education [42]	• Purpose: To enhance teacher candidates' algorithmic thinking and STEM awareness in the digital age. STEM-focused physical computing activities utilizing Arduino were examined to determine their effects on the said capabilities and the candidates' pros and downsides. • Study type: Mixed methods.	• STEM-focused physical computing activities, particularly those involving Arduino, dramatically enhanced algorithmic thinking skills and raised STEM awareness among teacher candidates. • The activities also provided practical insights into student-teacher roles as well as perceived benefits and drawbacks.

	• Respondents: 24 volunteer student-teachers • Data analysis: Pretest and post-test (STEM awareness) and qualitative data were collected to analyze student-teacher roles and their opinions on the activities' pros and cons.	• This study verifies the use of these exercises in improving algorithmic thinking and STEM awareness, making them beneficial in developing teaching techniques for aspiring science teachers.
Theme 2: Barriers, Perceptions, and Motivation in STEM Learning		
Title	Methodology	Results
Children building and having fun while they learn geometry [43]	• Purpose: To improve primary school children's performance in geometry • Methodology: Gamification and digital activities in virtual environments to teach geometry. • Implementation: Students participated as architects, manipulating 2D and 3D shapes to build structures. • The efficiency of the method was assessed through the experiences of 60 youngsters.	• Enhanced Learning and Interest: The system improved students' learning and increased their interest in math. • The technique improved pupils' understanding of geometry, from simple shapes to complicated 3D characteristics. • Both children and teachers rated the experience favorably, indicating the success of incorporating gamification and digital activities in geometry instruction. • Increased Engagement: Interactive learning and enjoyable aspects successfully engaged children in geometry.
Examining Students' Perceived Competence, Gender, and Ethnicity in a Digital STEM Learning Game [44]	• Purpose: To examine the effect of gender, ethnicity, and perceived competence on the learning, performance, and delight of students in a digital STEM learning game. • Study type: Quantitative • Data Collections: Demographic surveys, matched pre- and post-tests, and satisfaction questionnaires. • Respondents: 199 eleventh graders. • Six science classes utilized a 2D digital STEM learning game.	• The study found no significant interaction between gender and ethnicity in terms of perceived competence, performance, and delight in digital STEM learning activities. • Men showed greater perceived competence and in-game performance than females, while White and Hispanic students performed better than Black/African American students. • After controlling perceived competence and pretest scores, neither race nor gender significantly impacted performance. • Perceived competence and prior knowledge were found to play a greater role in performance and enjoyment.
Rethinking Entrepreneurial Education: The Role of Digital Technologies to Assess Entrepreneurial Self-Efficacy and Intention of STEM Students [45]	• Purpose: To examine if online courses can enhance students' entrepreneurial self-efficacy and intentions, similar to face-to-face education, and assess the impact of digital technologies during the COVID-19 pandemic. • Study type: Two-stage quali-quantitative analysis. • Respondents: 210 engineering students who took a 16-week online entrepreneurship course.	• The online entrepreneurship course's digital technology increased students' self-efficacy and entrepreneurial inclinations. • Ad hoc digital tools benefit project and business plan development in entrepreneurship education programs. • The study suggests that digital tools can improve university entrepreneurship education in the digital age. • The study highlights the need to improve university entrepreneurship teaching using digital technologies to improve learning results.
Teacher Perceptions on Virtual Reality Escape Rooms for	• Purpose: To explore the perceptions of K-12 in-service instructors regarding the use of a digital educational escape room in virtual reality (VR) and to identify its potential	• In STEM education, digital instructional escape rooms in VR may improve cognitive benefits and learning results. • The study found numerous issues

STEM Education [46]	benefits and drawbacks in learning environments. • Study type: Mixed method • Participants: 41 educators from grades K-12 • Data collections: Validated survey questionnaire and an online debriefing session.	instructional designers should address when incorporating technological solutions in different learning situations. • It suggests more systematic professional development to encourage teacher-led VR STEM activities. • In-service teachers liked VR educational escape rooms but said instructional design ideas must be carefully integrated.
Robotics Education in STEM Units: Breaking Down Barriers in Rural Multigrade Schools [30]	• Purpose: To explore how knowing about robotics helped students in different grades learn more about science and math and how the students felt about using robots to learn science and math. • Study type: Exploratory qualitative • Participants: 12 multigrade rural students • Data collection: Focus groups and semi-structured interviews	• The proposal outlines a strategy to mitigate inequalities in rural schools by introducing cutting-edge classroom technologies. • It seeks to provide equal access to educational robotics to all children, regardless of location or socioeconomic status, to reduce societal disparities. • Using a STEM-based methodology, the study presents an alternative method for incorporating educational robotics into rural institutions. • This strategy is intended to enhance learning in mathematics and science across multiple grade levels, fostering the acquisition of skills and knowledge relevant to the 21st century.
Measuring and Activating iSTEM Key Principles among Student Teachers in STEM [47]	• Purpose: To examine the implementation of integrated STEM education (iSTEM) using CODEM, a digital collaborative learning environment designed to help teachers deliver high-quality iSTEM education and boost student STEM engagement and proficiency. • Methodology: Implementing CODEM, a digital collaborative learning environment, for integrated STEM teaching.	• Increased iSTEM Immersion: Cooperative design in diverse teams helped student instructors learn iSTEM principles. • CODEM promoted integrated learning by integrating STEM disciplines for a unified learning experience. • Incorporating iSTEM principles, including problem-centered, modeling, inquiry-based, design-based, and cooperative learning, led to diverse learning experiences.
Differentiated instruction in digital video games: STEM teacher candidates using technology to meet learners' needs [48]	• Purpose: To explore how STEM teacher candidates may utilize technologically enhanced differentiated instruction (DI) in teacher education courses by creating digital video games (DVGs). It examined DVGs' inclusion and efficacy for DI in secondary science classes. • Methodology: Analysed eight DVGs created by teaching candidates. It assessed how well TCs integrated DI practices into their DVGs and how well DVGs implemented DI.	• Most TCs integrated DI practices within their DVGs. • DVGs helped differentiate instruction by facilitating pacing variation, difficulty levels, scaffolding, and multimodal content presentation. • DVGs represented diverse learners and promoted conceptual understanding with engaging features. • DVGs allow formative and diagnostic tests to meet individual learning requirements and academic achievement levels. • The research emphasizes using DVGs to meet students' needs, interests, and profiles.
Teacher's Perceptions of STEM Education at the Primary	• Purpose: To examine how digital programs can promote active and independent learning in elementary education more effectively than paper-based techniques,	• Most participating teachers supported the use of ICT in teaching. • Improvement in Teaching & Learning: ICT enhanced teaching and learning quality,

Level in Morocco [49]	fostering a student-centered approach. • Study type: Quantitative • Data collections: Questionnaire • Respondent: 80 primary school teachers for data collection	promoting a proactive learning culture among young learners. • The use of ICT in education has been shown to promote active and autonomous learning, resulting in a student-centered approach. • For primary schools, digital programs are favored due to their ability to satisfy contemporary educational expectations and efficiently teach key technological concepts.
Motivating youth to learn STEM through a gender-inclusive digital forensic science program [50]	• Purpose: To explore the Cyber Sleuth Science Lab (CSSL), a virtual learning program, to investigate technology-related social concerns using real-world digital forensic tools • Methodology: In-school and out-of-school pilots were conducted with racial minority students. • Study type: Mixed methods.	• Effectiveness: CSSL's virtual learning environment taught digital forensics well. • Engagement & Inclusion: CSSL gender-inclusive STEM training engaged females without affecting boys. STEM education using digital forensic science engaged girls by solving real-world challenges. • Career Interest: Girls were more interested in digital forensics and cybersecurity careers than boys after participation. • The program helped participants understand complicated technology-related societal concerns and improve their cyber street smarts.

Theme 3: Interdisciplinary and Cross-cultural Approaches in STEM Education		
Title	Methodology	Results
Geometry with a STEM and Gamification Approach: A Didactic Experience in Secondary Education [31]	• Purpose: Utilizing a gamified approach in STEM disciplines, particularly geometry. Integrating innovative technologies and learning strategies into secondary education teaching methods • Study type: Mixed method. • Methodology: Used AR, VR, manipulative materials, social networks, m-learning, cooperative learning, and flipped learning. • Data analysis: Analyze learning, strategies, successes, failures, and questionnaire results.	• The new strategy improved academic performance from 50% to 100%, resulting in full-group engagement, higher motivation, and a positive emotional response. • It also enhanced group cohesion, boosted student engagement, and integrated teaching methods with modern student preferences. • The methodological transformation was validated, including active methods, ICT, and gamified approaches.
Exploring How Secondary STEM Teachers and Undergraduate Mentors Adapt Digital Technologies to Promote Culturally Relevant Education during COVID-19 [51]	• Purpose: The goal is to understand how digital tools and collaborative pedagogies may promote equitable and relevant STEM learning. • Study type: A qualitative multi-case research. • Data Collection: Describes three teacher-undergraduate mentorships. • Data Analysis: A cross-case analysis interpreted various technologies, pedagogy, and content usage for equal student outcomes in diverse learning environments.	• Teachers and undergraduates successfully adapted to remote and hybrid learning models during the pandemic, enhancing learning experiences through digital tools and collaborative pedagogies. • They scaffolded technology use and content application, providing constant feedback for student knowledge and application. • This approach improved distant and hybrid student learning outcomes, promoting adaptability and equity in post-pandemic education scenarios.
Creativity Development with Problem-	• Purpose: To examine how problem-based Digital Making (DM) programs might enhance student creativity in STEAM	• Problem-based digital storytelling (DM) activities in K-12 education have enhanced students' creativity, with Scratch playing a

Based Digital Making and Block-Based Programming for Science, Technology, Engineering, Arts, and Mathematics Learning in Middle School Contexts [52]	education. To examine how Scratch helps middle school pupils express their creativity. • Study type: Qualitative (case study) • Participants: 54 Hong Kong middle school students (10-14 years old) • Methodology: The program lasted five weeks and ten contact hours and used the block-based programming tool Scratch.	significant role in mediating their solutions. • However, the tool has limitations that hinder the construction of digital artifacts. • The study provides theoretical and practical insights for implementing DM in K-12 education. It suggests its integration in STEAM learning can cultivate creativity, but carefully considering tools and methods is needed to overcome limitations.
How to foster STEM learning during COVID-19 remote schooling: Combining virtual and video experiments [25]	• Purpose: To evaluate if virtual and video experiments improve physics conceptual knowledge more than virtual experiments alone. • Respondent: 154 seventh graders who attended remote school during the COVID-19 pandemic. • Approach: Students used virtual and video experiments in two orders or solely virtual experiments for inquiry learning.	• Inquiry learning improves students' conceptual knowledge of physics. • Combining virtual and video tests, on the other hand, was not more effective than utilizing solely virtual experiments. • Virtual and video experiments are recommended for teachers when hands-on experimentation is unavailable due to pandemics. • When traditional approaches are ineffective, the study emphasizes the role of digital technology in sustaining learning and increasing understanding of scientific concepts.
Modern approaches to teaching future teachers of mathematics: the use of mobile applications and their impact on student's motivation and academic success in the context of STEM education [53]	• Purpose: To investigate the efficiency of standard teaching methods versus the MalMath app in teaching mathematics. • Participants: 72 students • Study type: A quasi-experimental • Methodology: Students were split into two groups: an experimental group utilizing MalMath and a control group using traditional teaching methods. • Data Analysis: Academic achievement and learning motivation were examined, and the t-test was used to evaluate significance.	• The study found that students who used the MalMath app did much better in school and were more interested in learning than students in the control group. • The results match those of other scientific papers, which show that the MalMath app has a good effect on how well students do in school and how motivated they are to learn. • The results show that mobile math apps like MalMath could be studied and used in more ways to help people learn math, and they also have theoretical implications for more research on mobile math apps.
The influence of a STEM-based digital classroom learning model and high-order thinking skills on the 21st-century skills of elementary school students in Indonesia [54]	• Purpose: To create a STEM-based digital classroom learning model concentrating on 21st-century skills for elementary school pupils. To examine the impact of STEM and Higher-Order Thinking Skills (HOTS) on elementary children's 21st-century skills. • Study type: Quantitative (experimental) • Respondents: 100 fourth-grade pupils • Data analysis: SPSS was used to analyze the acquired data using two-way ANOVA testing, homogeneity tests, normality tests, and descriptive tests.	• Pupils exposed to STEM-based digital learning models demonstrated different 21st-century competencies than those taught using traditional methods. • Higher order thinking skills differed across pupils of different levels. • A link was discovered between 21st-century skills and the sort of learning model used, particularly among students with various levels of higher-order thinking skills.

5. Discussion and Conclusion

5.1 Digital Integration and Innovation in STEM Education

Using cutting-edge digital tools and approaches, such as digital escape rooms and different technology apps, has measurably improved STEAM education by encouraging participation, creative thinking, and critical problem-solving abilities. These innovations help to demystify STEM disciplines, making them more accessible and interesting to a broader spectrum of students and functioning as change agents in learning paradigms. However, difficulties such as balancing digital competency, reducing distractions, and ensuring equal accessibility demand careful thinking and strategy. The significance of improved digital literacy among educators and students alike is emphasized as a critical component for maximizing the advantages of technology in education. Numerous research findings emphasize the importance of a nuanced approach to integrating technology in learning processes, assuring the balanced, equitable, and successful use of digital technologies in various educational situations.

5.2 Barriers, Perceptions, and Motivation in STEM Learning

To overcome the obstacles in STEM learning, it is essential to conduct a comprehensive examination of the intricate relationship between limited resources, deeply ingrained societal stereotypes, and widespread educational disparities. The research being examined provides insight into the obstacles in different situations. For example, the differences in performance between genders and ethnic groups in digital STEM games not only highlight social prejudices but also prompt inquiries regarding fair allocation of resources. The potential benefits of digital tools are limited by the actual obstacles they provide, such as problems with accessibility and hurdles in incorporating them into the curriculum. These constraints are particularly evident in financially restricted and rural educational environments. These findings indicate a pressing requirement for research that concentrates on creating instructional technology that is inclusive and accessible to everyone. Moreover, the research indicates that simply providing digital tools is not enough without simultaneous investments in professional development for educators, guaranteeing that they are adequately prepared to make the most of this technology. An essential approach for achieving actual scientific progress in addressing the educational hurdles shown by this research is the implementation of a dual strategy that focuses on empowering teachers and democratising technology.

5.3 Interdisciplinary and Cross-Cultural Approaches in STEM Education

The research papers conclusively show that strategically incorporating digital technologies and approaches into the educational environment may greatly improve learning experiences and outcomes. Innovative tactics, such as gamified approaches and ICT, have proven critical in increasing academic engagement, motivation, and performance and creating positive emotional reactions and flexibility in various learning situations. The success of programs like MalMath, which have demonstrated the transformational power of digital tools in generating interest and raising scholastic attainment in disciplines like mathematics, is especially significant. However, these digital tools and methodologies must be carefully selected and applied for the best outcomes to overcome inherent limits and develop crucial 21st-century skills and competencies. In summary, these findings highlight

the critical importance of digital advances in aligning educational techniques with current requirements, improving education's overall quality and relevance in the modern period.

5.4 Overall Conclusion

Digital improvements in STEM education have increased participation, understanding, and demystification of previously complicated topics, changing educational paradigms. Digital escape rooms, game-based learning, and collaborative platforms like CODEM have improved educational inequality and engagement, but digital proficiency, distraction reduction, and equitable access remain issues. Future educators must prioritise extensive and ongoing professional development in digital tool use and innovation. Future research and strategy should emphasise student co-design of digital tools and curriculum to guarantee relevance and engagement, underpinned by strong research to develop methodology and efficacy. Future STEM education must also ensure fair access and incorporate global and cross-cultural viewpoints to improve global proficiency. The educational framework should incorporate ethical use and data privacy to protect stakeholders and create an ethical digital learning environment. Future paths should focus on inclusive, ethical, and internationally relevant digital STEM education that combines innovation, accessibility, and ethics.

The article concludes that technology significantly eases and enhances the teaching and learning process by providing accessible information and creating enjoyable learning opportunities. The use of technology is lauded for improving educators' instructional methods, productivity, and teaching efficiency. Most students recognize the importance of technology in learning mathematics as it adds an element of fun, increases motivation, boosts confidence, and supports independent learning. Despite the prevalent use of various applications and websites developed to aid mathematics learning, students still prefer to initially work through problems on paper and subsequently use technology to verify their solutions. The incorporation of technology in the classroom is acknowledged to foster innovation and prepare students for future learning and education, all the while ensuring they acquire vital 21st-century skills.

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