

Integrating Stem Education with Digital Storytelling in Primary Education: A Systematic Review Across Four Mediterranean Countries

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Abstract

This systematic review examines the integration of STEM education with digital storytelling for learners aged 6-12 years across Türkiye, Portugal, Italy, and Spain. The review analyses 38 peer-reviewed studies published between 2017 and 2023, exploring methodological approaches, sample characteristics, thematic focuses, integration strategies, and key findings. Data were collected from international databases (EBSCO, ERIC, Scopus, Web of Science) and national repositories, and studies were selected based on rigorous inclusion criteria emphasizing STEM-digital storytelling integration, detailed methodology, and contextual information. The analysis reveals diverse methodological approaches: Turkish studies predominantly employ mixed-methods quasi-experimental designs; Portuguese research emphasizes teacher professional development and pandemic-related adaptations; Italian studies focus on qualitative case studies examining creativity and emotional expression; and Spanish research uses varied designs to address social-emotional skills and educational inclusion. Findings demonstrate that integrating digital storytelling into STEM education consistently enhances academic achievement, student engagement, and motivation across all contexts. The approach effectively develops 21st-century competencies, including critical thinking, problem-solving, and collaboration, while addressing student misconceptions and facilitating deeper conceptual understanding. Digital storytelling emerges as both a pedagogical tool and epistemological framework that bridges abstract STEM concepts with meaningful, contextually relevant learning experiences. However, implementation challenges persist, particularly regarding time requirements, teacher preparation, and technological infrastructure. The review demonstrates digital storytelling's capacity to address both cognitive and affective learning dimensions while supporting student well-being. Future research requires longitudinal studies, the development of theoretical frameworks, and comprehensive teacher-training models to fully realize the transformative potential of this integrated approach in primary education.

Keywords: Cross-Cultural Research, Digital Storytelling, Educational Technology, Primary Education, STEM Education

Questa revisione sistematica esamina l'integrazione dell'educazione STEM con la narrazione digitale per studenti di età compresa tra 6 e 12 anni in Turchia, Portogallo, Italia e Spagna. La revisione analizza 38 studi sottoposti a revisione paritaria pubblicati tra il 2017 e il 2023, esplorando approcci metodologici, caratteristiche del campione, focus tematici, strategie di integrazione e risultati chiave. I dati sono stati raccolti da database internazionali (EBSCO, ERIC, Scopus, Web of Science) e archivi nazionali, e gli studi sono stati selezionati sulla base di rigorosi criteri di inclusione che enfatizzano l'integrazione STEM-narrazione digitale, una metodologia dettagliata e informazioni contestuali. L'analisi rivela diversi approcci metodologici: gli studi turchi impiegano prevalentemente progetti quasi sperimentali con metodi misti; la ricerca portoghese enfatizza lo sviluppo professionale degli insegnanti e gli adattamenti legati alla pandemia; gli studi italiani si concentrano su casi di studio qualitativi che esaminano la creatività e l'espressione emotiva; e la ricerca spagnola utilizza progetti diversi per affrontare le competenze socio-emotive e l'inclusione educativa. I risultati dimostrano che l'integrazione dello storytelling digitale nell'educazione STEM migliora costantemente il rendimento scolastico, il coinvolgimento e la motivazione degli studenti in tutti i contesti. L'approccio sviluppa efficacemente le competenze del XXI secolo, tra cui il pensiero critico, la risoluzione dei problemi e la collaborazione, affrontando al contempo le idee sbagliate degli studenti e facilitando una comprensione concettuale più profonda. Lo storytelling digitale emerge sia come strumento pedagogico che come quadro epistemologico che collega concetti STEM astratti con esperienze di apprendimento significative e contestualmente rilevanti. Tuttavia, persistono difficoltà di implementazione, in particolare per quanto riguarda i requisiti di tempo, la preparazione degli insegnanti e l'infrastruttura tecnologica. La revisione dimostra la capacità dello storytelling digitale di affrontare sia le dimensioni cognitive che quelle affettive dell'apprendimento, supportando al contempo il benessere degli studenti. La ricerca futura richiede studi

longitudinali, lo sviluppo di quadri teorici e modelli completi di formazione degli insegnanti per realizzare appieno il potenziale trasformativo di questo approccio integrato nell'istruzione primaria.

Parole chiave: Ricerca interculturale, Narrazione Digitale, Tecnologia Educativa, Istruzione Primaria, Istruzione STEM

1. Introduction

The integration of Science, Technology, Engineering, and Mathematics (STEM) disciplines into educational curricula has been empirically demonstrated to yield significant cognitive, procedural, and attitudinal benefits for learners (Martín-Páez et al., 2019). Furthermore, research by Ismail (2018) indicates that STEM education extends beyond pedagogical advantages to encompass substantial economic benefits, including enhanced professional development opportunities, improved capacity to meet evolving workplace demands, the promotion of sustainable employment practices, the development of innovative secondary education models, and the facilitation of domestic economic growth. Given these multifaceted advantages, national governments worldwide are increasingly implementing STEM education initiatives to achieve several strategic objectives in their educational systems (Golegou & Peppas, 2025). These include enhancing performance on international educational assessments such as the Trends in International Mathematics and Science Study (TIMSS) and the Programme for International Student Assessment (PISA), expanding the population of students equipped with both fundamental and advanced competencies in science and technology, and increasing the number of graduates in science and mathematics fields (Widya & Laila Rahmi, 2019). Moreover, governmental adoption of STEM education is frequently driven by pragmatic economic considerations, such as addressing economic downturns, developing human capital to support industrial advancement and modernization, strengthening competitive positioning in the global marketplace, and reducing unemployment rates (Ismail, 2018). Despite these well-documented benefits and widespread implementation, significant conceptual challenges persist within the field. Specifically, considerable ambiguities remain regarding the precise definition, theoretical conceptualization, operational scope, and practical implementation of STEM education, particularly within the context of primary education (Basham & Marino, 2013; Brown et al., 2011; Falloon et al., 2020; Kloser et al., 2018; Sgro et al., 2020). These conceptual uncertainties present critical barriers to effective implementation and highlight the urgent need for comprehensive research to establish clearer frameworks for STEM education practice, particularly in elementary educational settings.

2. Literature Review

2.1. STEM Education

STEM education has experienced unprecedented global adoption and implementation over the past two decades, driven by widespread efforts to refine and advance contemporary educational practices (Gil & Sylla, 2022; Zhan et al., 2022). This surge in international interest has prompted numerous scholarly attempts to establish a comprehensive definition of STEM education. These definitional efforts can be categorized into two primary conceptual approaches: (1) the disciplinary approach, which advocates for incorporating educational components from each STEM discipline while emphasizing the collective significance of these distinct fields, and (2) the integrative approach, which prioritizes the interconnections between various STEM disciplines

to conceptualize STEM education as a holistic framework (Xie et al., 2015). Despite these ongoing definitional debates, contemporary educational research demonstrates a clear trend toward promoting the integration of STEM fields rather than maintaining disciplinary boundaries. This integrative perspective has gained considerable momentum in recent scholarship, with researchers increasingly advocating for interdisciplinary approaches that bridge the domains of science, technology, engineering, and mathematics (Bryan & Guzey, 2020; English, 2016; Portillo-Blanco et al., 2024; Roehrig et al., 2021). While multiple definitional frameworks coexist, the field demonstrates a clear trajectory toward integrated approaches that emphasize interdisciplinary connections over isolated disciplinary instruction.

Despite theoretical divergence in STEM education conceptualization, educational stakeholders have reached consensus on one fundamental concern: the critical need to enhance STEM competencies across diverse educational systems to address the global demand for qualified STEM professionals (Chao-Fernández et al., 2023; Kelley & Knowles, 2016). This workforce shortage has been exacerbated by significant economic challenges, underscoring the urgency of developing human capital in STEM fields (English, 2016) as well as by crisis challenges such as COVID-19, which affected schools all around the world and where teachers kept developing STEM activities using new strategies, revealing the main challenges and effects on student learning (Baptista et al., 2020). In light of this pressing global imperative, the ongoing definitional debates and efforts to establish “a single worldwide definition of STEM education” have become less crucial than identifying shared pedagogical components and creating equitable learning opportunities that enable all students to achieve STEM-related educational objectives (Holmlund et al., 2018, p. 17). Research has identified several core elements that characterize effective STEM education implementation. These fundamental components include the development of problem-solving capabilities (Morgado et al., 2025; Tan et al., 2023), the cultivation of critical thinking skills (Mater et al., 2022), and the enhancement of student engagement through active learning methodologies such as project-based learning (Hall & Miro, 2016) and problem-based learning approaches (Newhouse, 2017). Thus, while a definitional consensus remains elusive, the focus has shifted toward the practical implementation of research-based pedagogical strategies that foster essential STEM competencies across various educational contexts.

2.2. Significance of STEM Education in Primary Education

Although complete consensus remains elusive, the widely acknowledged objectives of STEM education encompass three primary goals: developing STEM literacy for all learners, equipping students with essential 21st-century skills such as problem-solving, critical thinking, creativity, and innovation, and advancing interdisciplinary competencies for effective problem-solving (Lin et al., 2023; Wan et al., 2023; Ong & Lee, 2023; Filipe et al., 2024). To achieve these educational objectives and prepare students for future challenges, introducing and implementing STEM education from the primary level has been recognized as highly beneficial (Kurup et al., 2019; Costa et al., 2022; Yim et al., 2024). Engaging young learners in STEM education enables educators to harness children’s natural curiosity and questioning tendencies while fostering the development of advanced STEM competencies (Isabelle & Valle, 2016; Ferraz-Caetano & Dias, 2021). Contemporary research has demonstrated that the effectiveness of STEM education with young learners can be significantly enhanced through the integration of various digital technologies, including augmented reality (Wang et al., 2024), virtual reality (Cromley et al., 2023), educational robotics (Bano et al., 2024), and artificial intelligence applications (Yang et al., 2024). Additionally, research focusing specifically on primary-aged learners has revealed that STEM education can be effectively strengthened through targeted pedagogical tools, particularly digital storytelling approaches (Niemi & Niu, 2021; Sweeney-Burt, 2014; Yilmaz & Sigirtmac,

2023). Therefore, primary education emerges as a critical foundation for STEM learning, with digital technologies and storytelling tools offering promising pathways to engage young learners and achieve fundamental STEM educational objectives.

2.3. Digital Storytelling

Digital storytelling, initially conceptualized as short audio-visual streams combining pictures with first-person voice-over narration (Lambert, 2009, 2013; Gladstone & Stasiulis, 2017), has evolved into a more intimate and participatory approach to narrative creation in digital formats (McLellan, 2007). As an innovative pedagogical strategy, digital storytelling integrates instructional content with interactive learning activities to foster more engaging and stimulating educational environments that promote deep and meaningful student learning (Smeda et al., 2014). Robin (2008) defines digital storytelling as “a powerful teaching and learning tool that engages both teachers and their students” by enabling them “to become creative storytellers through the traditional processes of selecting a topic, conducting some research, writing a script, and developing an interesting story” (p. 222). Beyond its educational applications, digital storytelling serves a dual function: it operates both as a medium for conveying stories through digital platforms and as an established genre within the arts that has been successfully adapted for research contexts as an arts-based methodology (Boydell et al., 2015; de Jager et al., 2017; De Vecchi et al., 2016; Lenette, 2017; Raposo & Vairinhos, 2022; West et al., 2022). Thus, digital storytelling represents a versatile pedagogical and research tool that combines traditional narrative elements with modern digital technologies to enhance both educational engagement and scholarly inquiry.

Simply adding computers to traditional teaching methods provides very little value to students’ classroom experiences (Merzenich, 2007). In contrast, educational digital storytelling offers significant benefits by helping students develop essential 21st-century literacies, including digital, technology, information, and visual literacies. This approach also supports student-centered learning strategies such as technology integration, student engagement, reflection for deeper learning, and project-based learning. Moreover, digital storytelling effectively combines digital, oral, and written literacies while promoting language fluency, effective communication, self-expression, and creativity (Barrett, 2006; Di Blas, 2022; Ng et al., 2022; Ohler, 2008; Robin, 2008; Wu & Chen, 2020). Unlike superficial technology integration, digital storytelling has a positive effect on children’s scientific skills and provides a comprehensive framework that meaningfully enhances multiple aspects of student learning and literacy development (Al-Barakat et al., 2025).

2.4. Digital Storytelling and STEM Education

Digital storytelling has proven to be an effective and engaging method for teaching STEM subjects in primary education (Anand, 2023; Gómez Martín et al., 2026; Yeni et al., 2022). Research indicates that digital storytelling motivates students to learn and enhances their academic performance (Parsazadeh et al., 2021; Gómez Martín et al., 2026). This approach also provides students with opportunities to learn coding while developing their creative writing skills (Burke et al., 2010). The implementation of digital storytelling helps engage students in computational thinking (Burke & Kafai, 2012; Kordaki & Kakavas, 2017; Parsazadeh et al., 2021; Vinayakumar et al., 2018), enabling them to express themselves creatively while integrating writing skills with information technology knowledge (Burke et al., 2010). Additionally, digital storytelling can effectively foster students’ artificial intelligence literacy by helping them use and apply AI knowledge to solve real-world problems (Ng et al., 2022).

Beyond these technical benefits, digital storytelling is associated with authentic learning experiences (Di Blas, 2022), proves valuable for understanding complex STEM concepts in

technology (Hill & Grinnell, 2014), and improves students' academic self-regulation skills (Amirinejad & Rahimi, 2023). Furthermore, it has a positive impact on learners' attitudes toward science classes and increases their satisfaction with STEM learning (Saritepeci, 2021). These findings demonstrate that digital storytelling serves as a versatile pedagogical tool that enhances both technical competencies and learning engagement in STEM education.

Given the demonstrated potential of digital storytelling as a multifaceted pedagogical tool in STEM education, there is a clear need to examine how this integration has been implemented and studied across different educational contexts. This understanding becomes particularly important when considering cultural variations in educational practices and approaches to STEM learning. Therefore, the present research aims to provide a comprehensive analysis of the existing literature by systematically examining studies from Türkiye, Portugal, Italy, and Spain that focus on integrating STEM education with digital storytelling for primary-aged learners (ages 6-12) (Pombo & Marques, 2021). By examining research across diverse Mediterranean and European contexts, this study explores education through various cultural perspectives, identifying common patterns and unique approaches to implementing digital storytelling in STEM curricula. The research addresses five key questions related to methodological approaches, sample characteristics, thematic focuses, implementation strategies, and principal findings reported in the reviewed literature, with the ultimate goal of synthesizing current knowledge and identifying future research directions in this emerging field. Digital storytelling emerges as a promising tool for positively influencing STEM interest and perceptions of intellectual stereotypes among middle school students (El Chaabi & Younes, 2025). Today, as schools strive to meet educational standards, technologies such as virtual and augmented reality (VR/AR), artificial intelligence (AI), digital storytelling, and mobile learning tools are increasingly integrated into digital storytelling platforms. Embracing innovation, educators are increasingly examining how AI, AR/VR, and digital storytelling platforms can improve instructional quality and learner outcomes and evaluating their impact on student engagement, literacy development, interdisciplinary learning, and digital competence (Maarouf, 2025; Gómez Martín et al., 2026).

3. Method

This systematic review was designed to examine the integration of STEM education with digital storytelling in primary education across Türkiye, Portugal, Italy, and Spain. The review followed the systematic review methodology proposed by Norris and Ortega (2006) and subsequently applied by Peterson (2023) and adhered to the PRISMA 2020 guidelines (Page et al., 2021) to ensure transparency and reproducibility. Five specific research questions guided the review:

RQ₁: Research Methodologies and Approaches- What research methodologies, designs, and approaches have been employed in studies examining the integration of STEM education with digital storytelling for learners aged 6-12 years in Türkiye, Portugal, Italy, and Spain?

RQ₂: Sample Characteristics and Contexts- What are the characteristics of the samples investigated in these studies, including educational levels, age groups, and specific educational contexts?

RQ₃: Thematic Focus Areas- What are the primary thematic areas of focus in research on STEM-digital storytelling integration across the four target countries?

RQ4: Integration Strategies and Implementation- How has STEM education been integrated with digital storytelling for primary-aged learners (6-12 years) in different national contexts, and what specific pedagogical strategies and tools have been employed?

RQ5: Findings and Outcomes- What are the major findings, outcomes, and impacts reported in studies examining STEM-digital storytelling integration for this age group across academic achievement, student engagement, skill development, and implementation challenges?

To address these research questions, the review focused specifically on research conducted between 2017 and 2023 examining STEM education and digital storytelling for learners aged 6-12 years in the four target countries. The literature search was conducted between October 2023 and February 2024 as part of an Erasmus+ scientific research project. The process involved two phases. First, researchers from each participating country independently conducted comprehensive online searches using both international databases (EBSCO, Education Resources Information Clearinghouse, Scopus, and Clarivate Web of Science) and local databases (TÜBİTAK ULAKBİM). These databases were selected because they contain high-quality, peer-reviewed research publications relevant to the review topic (Smith & Lafford, 2009). The search employed the following keywords: STEM education, primary education, digital literacy, and storytelling. Additionally, each country's name was included as a keyword to ensure comprehensive coverage of relevant national research.

To ensure quality and relevance, studies were required to meet eight specific inclusion criteria adapted from Peterson (2023, p. 950): focus on STEM education and digital storytelling for 6-12-year-old learners; publication in English peer-reviewed journal publication; publication between 2017-2023; specific focus on digital storytelling and STEM education integration; detailed contextual information; comprehensive methodology reporting including subjects, data collection, and analysis methods; and findings directly relevant to the research objectives.

In addition to the methodological criteria outlined above, the content and scope of the selected publications were evaluated using additional criteria established by the research team, as shown in Table 1.

Table 1. Inclusion criteria.

Inclusion Criteria	Exclusion Criteria	Rationale
Research articles published in peer-reviewed journals indexed by the predetermined databases	Editorials, duplicate publications, book chapters, conference proceedings, theses, and dissertations	Ensure scientific quality, research rigour, and accessibility through established academic channels.
Studies published between 2017 and 2023	Studies published before 2017 or after data collection initiation	Capture contemporary developments and recent advances in the field
Studies in English	Studies in other languages	Enable comprehensive analysis of research from target countries while maintaining linguistic accessibility.
Empirical research studies	Theoretical/conceptual papers, literature reviews, and practical classroom guides	Ensure relevance to research objectives and focus on evidence-based findings.
Studies targeting 6-12-year-old learners	Research focusing on other age groups (e.g., adolescents, adults)	Maintain alignment with the primary education focus and research scope.
Studies examining digital storytelling as a pedagogical tool, material, or activity for STEM education	Research with other primary focuses (e.g., training, curriculum development without digital storytelling integration)	Ensure direct relevance to the integration of digital storytelling in STEM educational contexts.

Publications, including commentaries, editorials, reviews, reports, technical descriptions, and opinion pieces, that did not meet the established criteria were excluded from the review. This screening process resulted in 38 research papers being retained for detailed analysis. After identifying eligible publications, researchers conducted a preliminary analysis of the abstracts to verify adherence to the inclusion criteria. Subsequently, all selected publications underwent full-text review to ensure alignment with the research objectives. The selection process consisted of two stages: researchers initially identified relevant papers from their respective countries, followed by a collaborative process to determine the final set of papers. Each participating country reviewed studies published in English within its national research context. The final corpus comprised 38 studies distributed as follows: Türkiye (n = 10), Portugal (n = 8), Italy (n = 10), and Spain (n = 10). However, it is worth mentioning that Portugal has fewer references compared to the other countries, due to the limited number of published papers that fully adhere to the criteria established for inclusion in this review. Data analysis was conducted using a standardized analytical framework that captured key study characteristics, including author information, publication year, study objectives, methodology and design, sample demographics (educational level and age group), approaches to integrating STEM and digital storytelling, and principal findings. The results are organized according to the five research questions: (1) research methodologies and approaches employed, (2) sample characteristics and contexts, (3) primary

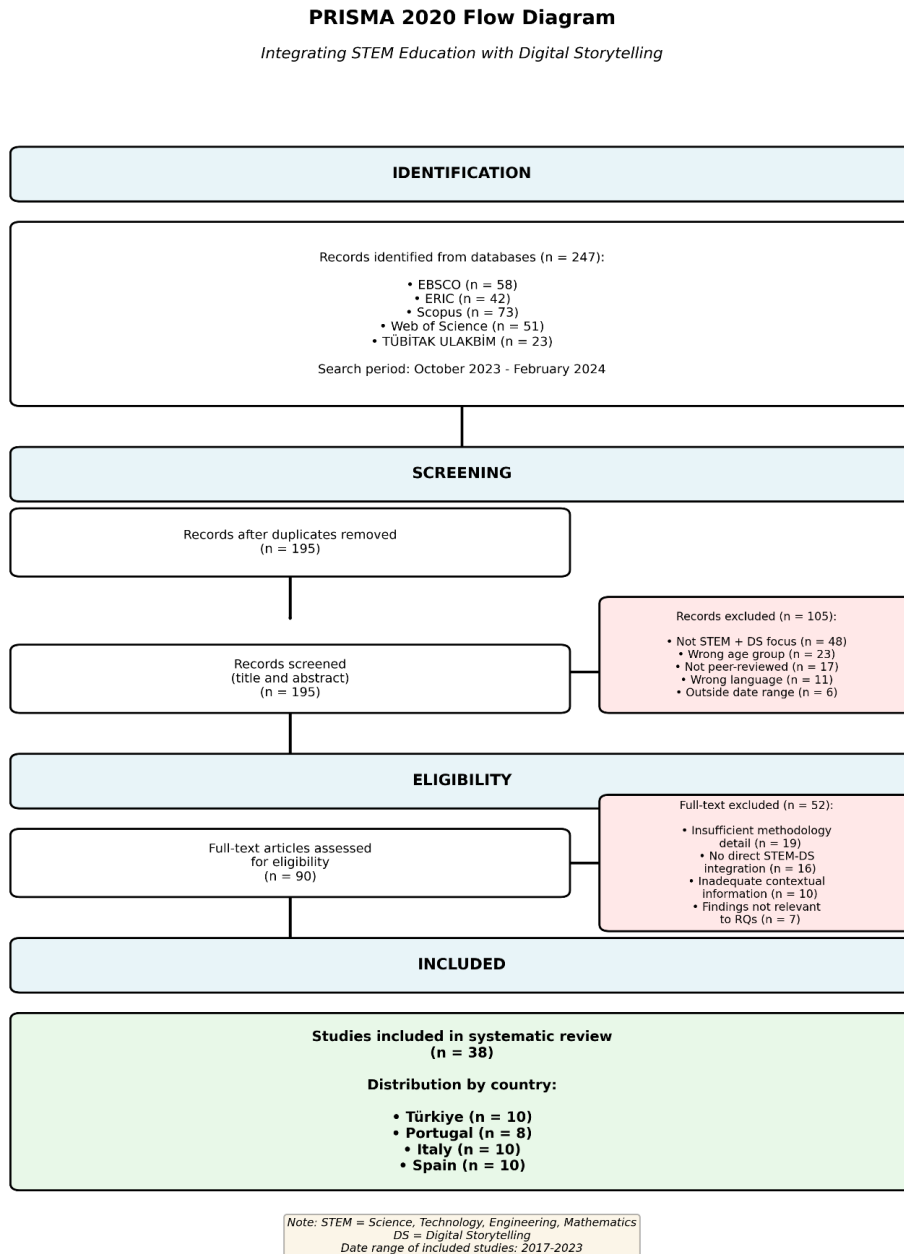
thematic areas of focus, (4) integration strategies for STEM education and digital storytelling with 6-12-year-old learners, and (5) key findings and outcomes reported in the literature.

3.1. Study Selection and Screening Process

The study selection process followed PRISMA 2020 guidelines (Page et al., 2021) to ensure transparency and reproducibility. The systematic search and selection involved four distinct phases: identification, screening, eligibility assessment, and final inclusion (see Figure 1). The comprehensive database searches conducted between October 2023 and February 2024 yielded a total of 247 records across five databases: EBSCO (n = 58), Education Resources Information Clearinghouse/ERIC (n = 42), Scopus (n = 73), Clarivate Web of Science (n = 51), and TÜBİTAK ULAKBİM (n = 23).

The search strategy employed the following keywords in combination: “STEM education,” “primary education,” “digital literacies,” “storytelling,” along with country-specific terms (“Türkiye,” “Turkey,” “Portugal,” “Italy,” “Spain”). All search results were exported to reference management software [Mendeley] for systematic screening. Following exportation, 52 duplicate records were identified and removed through automated and manual screening processes, resulting in 195 unique records for subsequent screening. Two independent reviewers from each participating country screened all 195 unique records by title and abstract against the predetermined inclusion criteria. During this phase, 105 records were excluded for the following reasons: lack of focus on STEM and digital storytelling integration (n = 48), inappropriate age group outside the 6-12 years range (n = 23), non-peer-reviewed publications (n = 17), publications not in English (n = 11), and studies outside the 2017-2023 timeframe (n = 6). This screening process resulted in 90 records deemed potentially eligible for full-text review. The full texts of the remaining 90 articles were retrieved and independently assessed by the same two reviewers from each country for eligibility against all inclusion criteria. During this comprehensive review, 52 articles were excluded for the following reasons: insufficient methodological detail preventing replication or assessment (n = 19), lack of direct focus on STEM-digital storytelling integration as the primary intervention (n = 16), inadequate contextual information about the educational setting or participants (n = 10), and findings not directly relevant to the research questions (n = 7).

To ensure the reliability and validity of the selection process, disagreements at any stage were resolved through discussion between the two reviewers. In rare cases where consensus could not be reached (n = 3), a third independent reviewer was consulted to make the final decision. Following the systematic screening and eligibility assessment, 38 studies met all inclusion criteria and were included in the final synthesis. These studies were distributed across the four target countries as follows: Türkiye (n = 10), Portugal (n = 8), Italy (n = 10), and Spain (n = 10). The complete study selection process is illustrated in Figure 1.



Two independent reviewers from each country conducted screening and eligibility assessment. Disagreements were resolved through discussion and consensus.

Figure 1. PRISMA 2020 flow diagram of the study selection process for the systematic review on integrating STEM education with digital storytelling in primary education across Türkiye, Portugal, Italy, and Spain.

4. Findings

The following subsections present the findings of the reviewed studies across four analytical dimensions: research strategies and methods employed, major areas of research focus, approaches to integrating STEM education and digital storytelling, and the principal findings reported across the four national contexts. The findings provide a consolidated cross-national overview of the key features across seven thematic parameters, as given in Table 2. These parameters offer a structured reference point for the detailed examination of studies in: research strategies and methods; academic achievement and learning outcomes; student engagement and motivation; 21st-century skills; emotional strategy and socio-emotional development; addressing misconceptions and conceptual understanding; interdisciplinary learning and collaboration; and identified gaps and barriers.

Table 2. Overview of the Reviewed Studies across National Contexts

Parameter	Türkiye	Portugal	Italy	Spain
Research Strategies & Methods	<ul style="list-style-type: none"> • Total studies: n = 10 • Mixed methods: n = 7 • Qualitative: n = 3 	<ul style="list-style-type: none"> • Total studies: n = 8 • Mixed methods: n = 2 • Qualitative: n = 6 	<ul style="list-style-type: none"> • Total studies: n = 10 • Mixed methods: n = 2 • Qualitative: n = 5 • Quantitative: n = 3 	<ul style="list-style-type: none"> • Total studies: n = 10 • Mixed methods: n = 2 • Qualitative: n = 8
Academic Achievement & Learning Outcomes	<ul style="list-style-type: none"> • Significantly higher scores in experimental groups in 4 out of 5 studies • One study was unable to establish a significant difference, yet still recorded higher scores in the experimental group • Positive effects on academic achievement across specific STEM subject areas 	<ul style="list-style-type: none"> • Students demonstrated better understanding of complex STEM concepts • Linking content to real-world scenarios, such as the COVID-19 pandemic, supported deeper conceptual comprehension 	<ul style="list-style-type: none"> • Blending storytelling with STEM subjects enriched students' understanding • Linking cognitive and emotional learning processes facilitated deeper engagement with STEM content 	<ul style="list-style-type: none"> • More practical and accessible STEM approaches improved students' acquisition of STEM concepts
Student Engagement & Motivation	<ul style="list-style-type: none"> • Integration made STEM topics more interesting, enjoyable, relevant, and relatable • Student and teacher reflections indicated positive responses to the integrated approach 	<ul style="list-style-type: none"> • Significantly improved student engagement and motivation across various age groups • Teachers reported increased motivation when students actively participated in creating digital narratives 	<ul style="list-style-type: none"> • Game-based storytelling enhanced student interest in STEM disciplines • The Future Inventors project integrated cognitive learning with emotional engagement 	<ul style="list-style-type: none"> • Digital tools fostered active and personalised learning • Digital storytelling addressed students' emotional needs, enhancing motivation and self-esteem • Students showed initial interest alongside perceived difficulty barriers
21st-Century Skills	<ul style="list-style-type: none"> • Positive influences on students' critical thinking skills 	<ul style="list-style-type: none"> • Storytelling improved problem-solving and critical thinking through creative STEM exploration 	<ul style="list-style-type: none"> • Digital storytelling projects developed critical thinking, empathy, and socio-emotional skills 	<ul style="list-style-type: none"> • Digital storytelling enhanced emotional intelligence and language skills

Parameter	Türkiye	Portugal	Italy	Spain
		<ul style="list-style-type: none"> • Inquiry-based learning and cooperative projects fostered higher-order thinking skills 	<ul style="list-style-type: none"> • Use of Minecraft fostered critical thinking, problem-solving, and digital literacy 	<ul style="list-style-type: none"> • Collaborative storytelling strengthened creativity and social skill development
Emotional Literacy & Socioemotional Development	Not explicitly addressed in the reviewed studies	Not explicitly addressed in the reviewed studies	<ul style="list-style-type: none"> • Storytelling supported primary students in processing feelings of isolation and emotional distress during the COVID-19 pandemic • Students articulated their experiences and developed emotional resilience through narrative expression • Digital storytelling addressed both educational objectives and socioemotional needs 	<ul style="list-style-type: none"> • Storytelling supported children’s emotional well-being during the COVID-19 pandemic • Students used narrative tools to process challenging experiences and maintain social connections • Inclusive strategies facilitated the development of linguistic and emotional skills
Addressing Misconceptions & Conceptual Understanding	<ul style="list-style-type: none"> • Integration eliminated student misconceptions about fractions in mathematics • Digital storytelling facilitated the concretisation of abstract concepts 	<ul style="list-style-type: none"> • Digital storytelling reduced student misconceptions, particularly in mathematics • Students visualised abstract concepts through narrative-based learning 	<ul style="list-style-type: none"> • Social interaction and digital narratives supported conceptual learning and collaborative problem-solving in mathematics 	Not explicitly addressed in the reviewed studies
Interdisciplinary Learning & Collaboration	Not explicitly addressed in the reviewed studies	<ul style="list-style-type: none"> • Integration facilitated collaborative learning, with students working together to develop and present their stories • STEM tasks connected multiple disciplines through collaborative digital platforms 	<ul style="list-style-type: none"> • Digital storytelling served as a vehicle for interdisciplinary learning, offering academic benefits and personal growth • Interdisciplinary initiatives merged scientific inquiry with creative expression 	<ul style="list-style-type: none"> • Storytelling and STEM project-based learning enabled exploration of complex topics in creative and meaningful ways • Holistic, inclusive, and effective learning experiences were created through interdisciplinary approaches
Identified Gaps & Barriers	<ul style="list-style-type: none"> • Designing digital stories proved time-consuming and demanding for teachers • Difficulties with excessive screen time were reported 	<ul style="list-style-type: none"> • Preparing digital stories was time-intensive, particularly for teachers unfamiliar with digital tools 	Not explicitly addressed in the reviewed studies	<ul style="list-style-type: none"> • The effectiveness of digital tools was dependent on adequate teacher training • Students showed initial interest while facing perceived difficulty barriers

4.1. Research Strategies and Methods Employed in Reviewed Studies

The systematic review examined research designs and methodological approaches employed across the four target countries between 2017 and 2023. The analysis reveals distinct methodological preferences across countries. In Turkish studies, mixed-methods research emerged as the predominant approach, accounting for 70% of the reviewed research from this context. A detailed examination of Turkish studies shows that half employed experimental designs, specifically quasi-experimental or single-group experimental approaches ($n = 5$). For instance, employing a quasi-experimental design with a control group, Arslan and Yıldırım (2021) examined the impact of an online science course for fifth graders that used digital stories and games generated with Web 2.0 tools. Based on mixed-methods research, they compared pre-test and post-test academic achievement and analyzed qualitative data gathered through interviews. In another quasi-experimental study, Bilen et al. (2019) investigated how integrating digital storytelling into science education influences sixth-grade students' motivation, attitudes toward science, and academic achievement. In doing so, they analyzed the pre-test and post-test achievement scores of the experimental and control groups, along with quantitative data collected through motivation and attitude scales, as well as qualitative data from student feedback forms. Three studies employed a case study methodology, while the remaining two included one action research study and one that provided limited methodological detail, indicating a mixed-methods approach. For example, in a case study, Korukluoğlu and Yucel-Toy (2022) examined the effect of a six-week science and technology club enhanced with digital stories as part of online extracurricular activities for elementary students, where students actively participated in creating digital stories based on predetermined topics. Several instruments, such as students' digital stories, grades, interview transcripts, and teacher reflections, were used for data collection. Using an action research design, Karaoglan Yilmaz et al. (2018) incorporated digital storytelling into math education, specifically targeting fourth-grade students' mistakes and misconceptions regarding fractions. Following a five-week digital story-supported implementation, they analyzed its impacts using qualitative data gathered through misconceptions form, observation notes, and interviews. As seen, various methodologies were preferred in prior research in Türkiye.

Portuguese research demonstrated a distribution across methodological approaches, with qualitative methods predominating; however, mixed-method designs have gained ground in recent years, reflecting the need for a comprehensive understanding of both educational processes and STEM learning outcomes. A representative example is the study by Costa et al. (2022), which employed a mixed-methods approach to evaluate a professional development program integrating STEM education with real-world scenarios. This research highlighted the critical importance of equipping teachers with effective implementation skills, particularly during the COVID-19 pandemic when educators were required to adapt to online teaching modalities. The study used multiple data collection methods, including surveys, participant observation, and reflective reports, revealing that teachers perceived the training as highly beneficial for improving both their pedagogical practices and student motivation levels. Similarly, Baptista et al. (2020) emphasized the significance of interdisciplinary STEM integration for addressing real-world problems, further supporting the trend toward comprehensive teaching strategies in Portuguese educational contexts. The mixed-methods approach provided researchers with a robust analytical framework for examining how teachers adapted STEM activities during challenging periods, ensuring continuity in student learning and engagement. These methodological trends in Portuguese research indicate a strategic focus on using diverse research approaches to enhance teaching practices while addressing the complexities of effective STEM education delivery in evolving educational landscapes.

Italian research predominantly employed qualitative methodologies, with case studies being the most frequently applied approach. This methodological preference enabled an in-depth

examination of the impact of digital storytelling when integrated with STEM education in authentic classroom contexts. The qualitative studies typically incorporated multiple data collection methods, including classroom observations, interviews with students and teachers, and content analysis of students' digital creations. A representative example is the research by Rutta et al. (2021), which employed a case study design to investigate comic-based digital storytelling within a Content and Language Integrated Learning (CLIL) framework. The study involved 18 primary school students and aimed to enhance both language acquisition and content comprehension while promoting collaborative engagement with STEM topics. The qualitative approach enabled researchers to capture the nuanced interactions between language learning and understanding STEM content. Several Italian studies adopted mixed-methods designs to provide more comprehensive insights into educational outcomes. These studies integrated quantitative measures, such as surveys assessing student attitudes and motivation, with qualitative data collection methods. This multi-dimensional approach enabled researchers to identify both measurable effects and contextual factors influencing the implementation of digital storytelling across diverse Italian classroom settings (Fadda & Salis, 2022; Roffi & Cuomo, 2022; Rutta et al., 2021; Rubino et al., 2018).

Spanish research demonstrated methodological diversity, employing various strategies to examine different aspects of STEM education in primary and secondary contexts. The predominant approach combined quantitative and qualitative methodologies, including descriptive, experimental, and quasi-experimental designs. The quantitative studies frequently used structured assessment tools to measure educational outcomes. For example, Valero-Matas and Coca Jiménez (2021) employed structured questionnaires and SPSS statistical analyses to assess students' perceptions of STEM subjects and evaluate the effectiveness of pedagogical interventions. This approach provided measurable data on student attitudes and learning outcomes. Qualitative research in the Spanish context often adopts action research and ethnographic methodologies. These studies combined classroom observations, semi-structured interviews, and content analysis to gain an in-depth understanding of educational dynamics. Researchers examined the implementation of innovative tools, including digital platforms, maker labs, and collaborative storytelling methodologies, adapted for different age groups (Alonso-Campuzano et al., 2021; Mateos et al., 2021). A notable characteristic of Spanish research was its focus on the development of creativity and socioemotional skills. Studies investigating digital escape rooms and digital storytelling emphasized the importance of gamification and collaborative learning approaches (Jiménez et al., 2020; Sanabria, 2022). These multi-dimensional research strategies enabled a holistic examination of educational practices, addressing specific student needs while creating engaging learning environments that foster both academic competencies and essential skills (Roig Telo et al., 2021; Tsortanidou et al., 2023).

4.2. Major Areas of Focus in Reviewed Research

Analysis of the research focus areas revealed that Turkish studies have primarily concentrated on measuring the educational impact of integrating STEM and digital storytelling. More than half of the reviewed studies from Türkiye ($n = 6$) examined the effects of STEM-oriented teaching integrated with digital storytelling on students' academic achievement and learning outcomes in specific subject areas. Among these achievement-focused studies, several adopted multiple research foci. Two studies combined academic achievement measurement with the exploration of students' and teachers' reflections on digital story-based implementations and their experiences. Two additional studies examined both academic achievement and students' attitudes and motivation toward the integrated approach. One study by Yildiz Durak (2018) examined the comprehensive impact on student participation, self-efficacy, and academic achievement in specific STEM subjects. The remaining Turkish studies addressed a diverse range

of focus areas. One study examined students' and parents' opinions regarding the implementation of digital storytelling in science education following a classroom intervention (Saritepeci, 2021). Another study, exclusively focused on pre-service teachers' views and experiences resulting from their science teaching practices using digital storytelling with preschool children, was conducted by Yilmaz and Sığirtmaç (2020). Two additional research areas identified were the development of students' creative thinking skills and the addressing of student misconceptions through integrated STEM and digital storytelling approaches.

Portuguese research has consistently focused on integrating STEM education with real-world scenarios and interdisciplinary approaches, particularly within the context of teacher professional development and pandemic-related educational challenges. The primary research emphasis centered on examining the dual impact of STEM education on both teacher pedagogical practices and student engagement and motivation. Studies such as those by Costa et al. (2022) have investigated how hands-on, project-based learning tasks that connect STEM subjects to real-world problems, including pandemic-related challenges, enhance students' interest and motivation in STEM fields. This research highlighted the effectiveness of contextually relevant STEM applications in promoting student engagement. The adaptation of STEM education to remote learning contexts emerged as another significant focus area. Baptista et al. (2020) examined how teachers maintained student engagement through online platforms during the COVID-19 pandemic, emphasizing the resilience and adaptability of STEM educational approaches. These studies concentrated on maintaining educational continuity and sustaining student interest in digital learning environments. A consistent theme across Portuguese research was the emphasis on problem-solving and critical thinking development through inquiry-based learning and cooperative projects, exemplified by Raposo and Vairinhos (2022) with an exploratory project grounded in a Framework for Innovation process model to improve engagement, creativity, and STEM interest. The integration of STEM disciplines was examined as a means of promoting higher-order thinking skills in authentic learning contexts. Additionally, Portuguese studies addressed teacher professional development needs, particularly focusing on equipping educators with the skills necessary to create effective interdisciplinary learning environments. This dual focus on teacher capacity building and student outcomes reflects the comprehensive approach adopted by Portuguese researchers in developing adaptable STEM education frameworks for evolving educational contexts.

Italian research demonstrated a distinct focus on fostering student engagement, creativity, and emotional expression through digital storytelling in STEM contexts. The research emphasis extended beyond traditional academic outcomes to encompass holistic student development and well-being. A representative example is the Future Inventors Project conducted by the Museo Nazionale della Scienza e della Tecnologia "Leonardo da Vinci," (Museo della Scienza e della Tecnologia, n.d.), which emphasised the aesthetic and experiential dimensions of STEM learning. This interdisciplinary initiative aimed to merge scientific inquiry with creative expression, encouraging students to explore scientific concepts through narrative approaches. The project created a comprehensive educational experience that integrated cognitive learning with emotional engagement. The COVID-19 pandemic context revealed an additional research focus on the therapeutic potential of digital storytelling. Studies such as Pinnelli et al. (2021) and Buccini (2024) investigated how storytelling could support primary students in processing feelings of isolation and emotional distress. Through narrative expression and collaborative storytelling exercises, students were able to articulate their experiences and develop emotional resilience. This therapeutic application highlighted digital storytelling as a valuable tool for supporting psychological well-being alongside academic development. Italian research thus positioned digital storytelling not merely as a pedagogical tool but as a comprehensive approach to student support, addressing both educational objectives and socioemotional needs during

challenging circumstances (Bonacini et al., 2019; Manganello & Baldacci, 2024; Pinnelli et al., 2021; Xanthoudaki et al., 2020).

Spanish research indicated diverse focus areas, primarily concentrating on the development of social-emotional skills, educational inclusion, and pedagogical innovation through the integration of technology. The studies reflected a comprehensive approach to education that addressed both cognitive and affective learning dimensions. Research on smart platforms in primary education emphasized the importance of fostering student interaction and adaptive learning. Studies highlighted the critical need for adequate teacher training to maximize the potential of educational technologies (Nieto-Márquez et al., 2020). This focus area underscored the relationship between technological implementation and teacher professional development. Another significant research emphasis involved examining student attitudes and perceptions toward STEM subjects. Studies such as those by Valero-Matas and Coca Jiménez (2021) investigated strategies to increase student motivation and improve learning outcomes through more practical, accessible STEM approaches. This research aimed to bridge the gap between student interest and STEM engagement. Narrative-based methodologies, particularly digital storytelling and collaborative storytelling, emerged as key focus areas for strengthening creativity, emotional expression, and collaboration among students. These approaches extended beyond traditional academic learning to enable personal expression and social skill development. During the COVID-19 pandemic, storytelling became particularly valuable for supporting children's emotional well-being, as students used narrative tools to process challenging experiences and maintain social connections (Alonso-Campuzano et al., 2021; Sanabria, 2022). Collectively, these research focus areas reflect the commitment of Spanish researchers to holistic educational approaches that integrate cognitive learning with students' personal and emotional development across diverse and evolving educational contexts.

4.3. The ways of integrating STEM education and digital storytelling for 6-12-year-old learners

Among the 10 studies conducted in Türkiye, six employed structured implementation plans for integrating digital storytelling into STEM education, actively engaging both teachers and students in the design of digital stories. These studies typically followed a consistent pedagogical approach: teachers and researchers first introduced digital storytelling concepts to their students. They demonstrated exemplary digital stories using various Web 2.0 tools, after which students created their own digital stories either individually or collaboratively under guided instruction. The implementation processes in these studies generally adhered to established frameworks for digital story creation and design (e.g., Robin, 2008; Robin & McNeil, 2012). Two additional studies focused on pre-service teacher education, where teacher candidates developed and implemented lesson plans incorporating digital stories for preschool science and environmental education. The remaining two studies used a different approach, employing digital stories created by teachers and researchers as instructional materials to support STEM learning. Notably, one study integrated digital storytelling within a specific mathematics curriculum component (Özpınar et al., 2017), while the other addressed student misconceptions about fractions through action research methodology, using digital storytelling-enhanced mathematics activities to remediate conceptual errors (Karaoglan Yılmaz et al., 2018).

In Portugal, the integration of STEM education with digital storytelling for 6- to 12-year-old learners has primarily focused on using real-world scenarios and collaborative digital platforms to enhance student engagement and understanding. Among these studies, Costa et al. (2022) demonstrated how primary school teachers implemented STEM tasks during the COVID-19 pandemic, using digital storytelling as a central pedagogical tool. Teachers guided students in

creating digital stories on STEM subjects such as mathematics and science, using real-life challenges, like the pandemic, to make learning more relevant and engaging. This integration was supported by Web 2.0 tools, enabling students to collaborate online in creating stories that explored STEM concepts. Additionally, Baptista et al. (2020) examined how teachers used digital storytelling within STEM activities to enhance students' problem-solving and critical thinking skills. Teachers played a crucial role in scaffolding the storytelling process, encouraging students to integrate STEM content into their narratives. These studies focused not only on academic achievement but also on fostering creativity, collaboration, and social-emotional development. Through digital storytelling, students contextualized STEM learning within their own experiences, enabling a deeper understanding of complex scientific concepts. Overall, the integration of digital storytelling in Portugal's STEM education demonstrates its potential to create interactive, student-centred learning environments that bridge the gap between technology and education (Morgado et al., 2025).

In Italian educational contexts, digital storytelling has been systematically integrated into STEM curricula through interactive and collaborative pedagogical projects. A prominent example involves the use of 'Minecraft' as an educational platform, which enabled students to engage with complex environmental issues, particularly climate change. Through the construction of digital ecosystems and the simulation of environmental scenarios, students gained an understanding of intricate scientific concepts in an immersive, engaging learning environment. This game-based storytelling methodology not only enhanced student interest in STEM disciplines but also fostered the development of critical thinking, problem-solving, and digital literacy competencies. Such innovative applications of storytelling platforms demonstrate how Italian educators have effectively adapted digital technologies to accommodate diverse learning requirements while creating inclusive STEM learning experiences that align with students' interests and contemporary real-world challenges (Abbate et al., 2020). Additionally, Italian research has explored the role of interactive digital storytelling approaches in mathematics education, showing how social interaction and digital narratives can support conceptual learning and collaborative problem-solving (Polo et al., 2019).

In Spain, the reviewed studies demonstrate various methodologies for integrating STEM education with digital storytelling, emphasizing approaches that foster active learning and student creativity. Research examining the 'Smile and Learn' platform highlights the implementation of interactive activities that combine gamification elements with STEM content. These activities enable students to explore scientific and mathematical concepts through interactive narratives, exemplified by the 'Green City' game, which promotes environmental sustainability through problem-solving (Smile and Learn). Furthermore, the development of personalized activities through learning analytics tools ensures that individual student needs are addressed, facilitating meaningful learning experiences aligned with their interests. Moreover, research on STEM integration indicates that cultivating vocations in these fields requires combining digital tools and interactive storytelling from early educational stages. This approach enables more dynamic engagement with complex concepts while facilitating the development of problem-solving and collaborative competencies (Valero-Matas & Coca Jiménez, 2021). Digital storytelling can address students' emotional needs, enhancing motivation and self-esteem as they acquire STEM concepts. Inclusive strategies, including specific accommodations for students with special educational needs, enable broader participation in STEM projects while facilitating the development of linguistic and emotional skills within supportive learning environments. Additionally, approaches to digital storytelling for STEM concept instruction have been identified, whereby narratives about scientific explorations and engineering challenges enrich learning through emotional connections to the subject matter.

4.3. The major findings of the reviewed research

The reviewed studies were systematically examined to identify the principal findings regarding the integration of STEM and digital storytelling across different levels of primary education. The primary common finding across the reviewed research studies was related to academic achievement and learning outcomes. The integration of digital storytelling in STEM education consistently demonstrated positive effects on academic achievement and learning outcomes across multiple national contexts. In Türkiye, four out of five quasi-experimental and single-group experimental studies revealed significantly higher scores among the experimental groups that involved integrated STEM and digital storytelling activities, with only one study unable to establish a significant impact, yet still maintaining higher scores in the experimental group (Özpinar et al., 2017). Similarly, Portuguese research by Costa et al. (2022) found that incorporating digital storytelling into STEM lessons helped students better understand complex concepts by linking them to real-world scenarios, such as the COVID-19 pandemic. Italian studies further corroborated these findings, with the “Future Inventors” project demonstrating that blending storytelling with STEM subjects enriched students’ understanding by linking cognitive and emotional learning processes (Abbate et al., 2020; Xanthoudaki et al., 2020). These consistent findings across diverse educational contexts provide evidence that digital storytelling represents a viable and effective approach for enhancing STEM learning outcomes in primary education settings.

Enhanced student engagement and motivation emerged as another consistent outcome across all reviewed national contexts. Turkish studies examining student and teacher reflections have shown that integration makes STEM topics more interesting, enjoyable, relevant, and relatable (Korukluoğlu & Yucel-Toy, 2022). Portuguese research similarly demonstrated significantly improved student engagement and motivation across various age groups, with teachers reporting increased motivation when students actively participated in creating digital narratives related to STEM subjects (Costa et al., 2022). Spanish studies using the ‘Smile and Learn’ platform confirmed that digital tools foster active and personalized learning in STEM activities, although students showed initial interest while facing perceived difficulty barriers (Nieto-Márquez et al., 2020; Valero-Matas & Coca Jiménez, 2021). These findings collectively suggest that digital storytelling serves as an effective pedagogical strategy for transforming traditionally challenging STEM content into more accessible and emotionally engaging learning experiences that resonate with students’ interests and developmental needs.

The development of 21st-century skills is another common finding among studies conducted in various countries. The integration consistently fostered critical thinking, creativity, and collaborative competencies across various educational contexts. Turkish research has demonstrated positive influences on students’ critical thinking skills, while Portuguese studies have found that the implementation of storytelling improves problem-solving and critical thinking by encouraging creative exploration of STEM content (Costa et al., 2022). Italian research emphasized that digital storytelling projects addressing socially relevant topics effectively developed critical thinking, empathy, and socio-emotional skills among students (Abbate et al., 2020; Xanthoudaki et al., 2020). Spanish studies identified digital storytelling as an effective strategy for enhancing emotional intelligence while improving language skills (Sanabria, 2022). This cross-national finding demonstrates that digital storytelling in STEM education serves a dual purpose, simultaneously developing both subject-specific knowledge and essential life skills that prepare students for success in an increasingly complex and interconnected world.

Several studies across different countries have highlighted the effectiveness of digital storytelling in addressing student misconceptions and facilitating a deeper understanding of concepts.

Turkish research revealed that integrating digital storytelling with STEM subjects proved particularly beneficial for eliminating student misconceptions about fractions in mathematics (Karaoglan Yilmaz et al., 2018). Portuguese studies by Baptista et al. (2020) similarly found that digital storytelling in STEM activities helped reduce student misconceptions, particularly in mathematics, where students could visualize abstract concepts through narrative-based learning. Turkish preschool studies reported that digital storytelling activities helped attract children’s attention and facilitated the concretization of concepts. The narrative structure inherent in digital storytelling appears to provide students with meaningful contexts that transform abstract mathematical and scientific concepts into more concrete, comprehensible representations, thereby addressing fundamental learning barriers in STEM education.

The reviewed studies consistently highlighted the potential for interdisciplinary learning and collaboration. Portuguese research demonstrated that integration facilitated collaborative learning, with students working together to develop and present their stories (Costa et al., 2022; Morgado et al., 2025). Italian research emphasized that digital storytelling serves as a powerful vehicle for interdisciplinary learning, offering both academic benefits and personal growth opportunities through narrative exploration and collaborative creation (Xanthoudaki et al., 2020; Abbate et al., 2020). Spanish studies underscored the importance of collaborative learning and interdisciplinary integration, noting that both storytelling and STEM project-based learning allow students to explore complex topics in creative and meaningful ways, creating holistic, inclusive, and effective learning experiences (Villalustre & del Moral, 2014). The convergence of narrative arts with scientific inquiry through digital storytelling thus breaks down traditional subject boundaries, fostering educational environments where students can develop both technical competencies and communication skills within collaborative frameworks.

Despite positive outcomes, consistent challenges emerged across national contexts, particularly regarding time requirements and teacher preparation. Turkish studies noted that designing digital stories proved time-consuming and demanding for teachers, and reported difficulties with excessive screen time (Korukluoğlu & Yucel-Toy, 2022). Portuguese research identified similar challenges, particularly the time-intensive nature of preparing digital stories, especially for teachers unfamiliar with digital tools (Costa et al., 2022; Morgado et al., 2025). Spanish studies emphasized that the effectiveness of digital tools depends on adequate teacher training, which is crucial to maximize classroom technology benefits (Nieto-Márquez et al., 2020). The universal nature of these implementation barriers suggests that the successful integration of digital storytelling in STEM education requires comprehensive professional development programs and institutional support to address both technical competency gaps and concerns about time allocation.

5. Discussion and Conclusion

This review has highlighted the emerging significance of integrating STEM education with digital storytelling in primary education across Türkiye, Portugal, Italy, and Spain. The examined studies reflect growing recognition that traditional, discipline-specific pedagogical approaches are insufficient for equipping students with the competencies, literacies, and mindsets required for the 21st century. Interdisciplinary, creative, and participatory strategies, particularly the integration of digital storytelling into STEM education, emerge as promising innovations with pedagogical, cognitive, and socio-emotional implications.

The reviewed literature demonstrates how digital storytelling functions as both a pedagogical tool and an epistemological framework. As a pedagogical tool, it enables students to engage with

complex STEM content in meaningful, contextually relevant ways. As an epistemological framework, it represents a shift toward multimodal, narrative-based learning that aligns with contemporary educational paradigms. The process of designing and producing digital stories involves topic selection, research, scriptwriting, utilization of multimedia tools, and narrative presentation. Each step requires critical thinking, collaboration, creativity, and reflection—core competencies of modern STEM education. The convergence of STEM and storytelling effectively bridges the gap between abstract knowledge and lived experiences. In primary education, particularly, students often struggle to comprehend decontextualized STEM concepts. By anchoring these concepts in narratives and engaging students in the creative process, educators create pathways for deeper cognitive processing, emotional investment, and enhanced motivation. Integrating scientific principles within stories about climate change, robotics adventures, or pandemic-related challenges not only improves comprehension but also renders learning more socially relevant and personally meaningful. Additionally, evidence from Portugal and Italy suggests that digital storytelling plays a crucial role in supporting emotional literacy and student well-being, particularly during periods of crisis. During the COVID-19 pandemic, digital storytelling served as a therapeutic medium through which students expressed anxiety, isolation, and resilience. In this context, storytelling transcended its instructional function to become a space for emotional processing, social bonding, and identity formation. This aligns with research in arts-based education, where digital storytelling has been recognized as a strategy for integrating affective and cognitive development, though further research insights are needed.

A key insight relates to the central role of teachers in facilitating integration. Educators are responsible not only for introducing STEM content but also for scaffolding the storytelling process, managing digital tools, and fostering collaborative dynamics. However, several studies report significant barriers, including insufficient digital competence, inadequate time for lesson planning, limited access to technological infrastructure, and curriculum rigidity. These challenges indicate systemic issues requiring policy reforms, institutional support, and targeted professional development programs. Teacher training models implemented in Portugal that focused on STEM integration during pandemic-induced distance learning provide compelling examples of how educators can be empowered to adopt innovative pedagogies. The review also raises important questions regarding equity and inclusion. STEM-digital storytelling integration has proven particularly effective in engaging students from diverse backgrounds, including those with neurodevelopmental disorders, students in rural or under-resourced schools, and learners from migrant families. The use of personal narratives enables these students to integrate their experiences, languages, and cultural references into classroom learning, thereby fostering a sense of belonging and agency. This suggests that digital storytelling could democratize STEM education, provided it is accompanied by equitable access to digital tools and inclusive pedagogical practices.

The review highlights a significant theoretical and methodological gap. While the empirical benefits of integrating STEM and digital storytelling are increasingly documented, theoretical models explaining why and how this integration works remain lacking. Most studies focus on outcomes, such as improved engagement or academic performance, without fully exploring the underlying cognitive, emotional, and sociocultural mechanisms. Future research should draw on frameworks from educational psychology, media studies, and narrative theory to better articulate the pedagogical rationale for this convergence. Additionally, from a methodological perspective, the reviewed studies reveal diverse research strategies, ranging from qualitative case studies and ethnographies (particularly in Italy and Spain) to quasi-experimental and mixed-method designs (which are more frequent in Türkiye and Portugal). This methodological diversity allows for a nuanced understanding of both processes and outcomes of STEM-digital storytelling

integration. However, the absence of large-scale, longitudinal, or comparative research limits the generalizability of findings and underscores the need for a more unified research agenda in this domain. Moreover, there is a need to move beyond descriptive accounts toward critical, transformative perspectives that question dominant STEM education paradigms and envision new epistemologies rooted in creativity, affect, and intersubjectivity. Besides, the integration of STEM and digital storytelling represents more than a didactic innovation; it signals a potential paradigm shift in primary education. This approach invites educators, researchers, and policymakers to reconceptualize learning as a dynamic, narrative, and collaborative process that honors both scientific and humanistic dimensions of knowledge. To harness its full potential, however, systemic changes are required: scalable teacher training, adaptable curricular frameworks, infrastructure investment, and a coherent research agenda that addresses complexity while striving for inclusivity and sustainability.

To conclude, integrating STEM education with digital storytelling provides a robust, holistic framework for transforming primary education. Drawing on empirical evidence from Türkiye, Portugal, Italy, and Spain, this approach demonstrably fosters cognitive engagement, emotional development, digital fluency, and interdisciplinary thinking—essential components of 21st-century learning. Digital storytelling enables the contextualization of STEM knowledge through narrative frameworks that are both personal and collective, thereby increasing relevance and retention. The reviewed studies demonstrate that when students collaboratively construct stories about scientific problems or real-life phenomena, they not only grasp disciplinary concepts more effectively but also develop cross-cutting competencies such as empathy, collaboration, and resilience. These findings are particularly relevant in the post-pandemic education landscape, where student motivation and mental health have become top priorities. Digital storytelling represents more than a complementary tool in STEM education; it constitutes a conceptual and methodological innovation with the power to transform educational experiences. By integrating emotional intelligence, creativity, and technological skills into STEM instruction, it redefines scientific learning in the digital age. This integration signals a paradigm shift, inviting educators, researchers, and policymakers to reconceptualize learning as a dynamic, narrative, and collaborative process that honors both the scientific and humanistic dimensions of knowledge. Investing in this integration means investing in inclusive, engaging, and future-oriented learning environments that empower all students to participate meaningfully in the scientific and technological challenges of our time. Nevertheless, several critical challenges persist. Teachers require sustained and systematic professional development to integrate storytelling with STEM in pedagogically sound and technologically feasible ways. Curriculum frameworks must evolve to recognize narrative, emotional, and creative dimensions as integral to scientific literacy. Educational systems must ensure equitable access to technology, infrastructure, and training, especially for underserved schools and vulnerable populations. From a research perspective, there is an urgent need for longitudinal, cross-national studies to track the lasting impact of this integration on student learning, identity formation, and future aspirations. More sophisticated theoretical work is necessary to bridge the gap between practice and theory, providing educators with models and guidelines for effectively implementing narrative-based STEM education.

6. Limitations and Future Research Directions

This systematic review has several limitations that should be considered when interpreting the findings. First, quality assurance was ensured through rigorous inclusion criteria requiring peer-reviewed publications with comprehensive methodological reporting, detailed contextual information, and findings directly relevant to the research questions. While this approach

established a minimum quality threshold, it does not provide the same level of systematic quality evaluation as formal risk-of-bias assessment tools. Incorporating a standardised quality appraisal framework, such as the Mixed Methods Appraisal Tool or the CASP checklist, would allow future reviewers to make more differentiated quality judgements and, in turn, draw more carefully calibrated conclusions from the evidence.

Second, the review relied exclusively on published peer-reviewed journal articles, which may overrepresent studies with positive or statistically significant findings. Grey literature sources such as dissertations, conference proceedings, technical reports, and unpublished studies were not systematically searched, potentially excluding valuable insights from ongoing or unsuccessful implementations of STEM-digital storytelling integration. This limitation is particularly relevant given that educational interventions with null or negative results are often underreported in academic literature. Future reviews that systematically incorporate grey literature would be better placed to capture this underrepresented side of the evidence, offering a more honest account of how integration actually functions when implementations do not proceed as expected.

Third, the search was restricted to English-language publications, despite the review's focus on four countries where English is not the primary language. This choice was shaped by both practical and methodological considerations. English is the predominant language of international scientific communication, but, more importantly, it served as the common working language among all project partners with different linguistic backgrounds. Adopting English as the sole search language ensured terminological consistency and reduced ambiguity during data extraction, both of which were genuine concerns given the diversity of national educational contexts represented in the corpus. That said, we recognise that this restriction may have led to the exclusion of relevant studies published in Turkish, Portuguese, Italian, or Spanish, which could have provided important contextual insights or alternative perspectives on the integration of STEM and digital storytelling. Future reviews in this area would benefit from adopting multilingual search strategies to ensure a more inclusive and geographically representative picture of the field.

Fourth, the review focused specifically on the 6-12 age range (primary education), which enhances focus and comparability but limits generalizability to other educational levels. The integration of STEM education with digital storytelling in early childhood education (0-5 years) or secondary education (13-18 years) may involve distinct pedagogical approaches, technological tools, and learning outcomes that are beyond the scope of this review. Research spanning a wider developmental range would help establish whether the outcomes identified here translate meaningfully to younger or older learners, or whether the approach requires substantial rethinking at different stages of education.

Finally, the temporal scope of the review (2017-2023) may not capture earlier foundational work in this area or more recent developments following the search period. The field of educational technology evolves rapidly, and newer tools, platforms, and pedagogical approaches may have emerged since data collection ended in February 2024. A search update to include post-2023 literature seems particularly timely given the rapid spread of AI-assisted learning environments in primary education, which is already reshaping how STEM content and digital storytelling tools are used in classrooms.

Taken together, these limitations point to a reasonably clear agenda for future work. Stronger quality appraisal tools, broader literature searches, and a broader temporal and developmental scope would each advance the evidence base. More importantly, they would help the field move beyond a picture of integration that is, at present, largely positive and largely Anglophone. Building a fuller picture, including research that captures mixed or null results and studies

conducted in the languages of the countries where this work actually takes place, seems essential if findings from reviews like this one are to inform practice in a genuinely meaningful way.

Despite these limitations, this systematic review makes important contributions to understanding the integration of STEM and digital storytelling in primary education. The comprehensive search across five databases, the inclusion of 38 studies from four countries, the systematic selection process involving independent reviewers, the detailed data extraction framework, and the comparative cross-country analysis provide valuable insights into current practices, outcomes, and implementation challenges. The findings offer a robust foundation for future research, teacher professional development initiatives, and policy decisions regarding technology-enhanced STEM education in primary schools.

Notes

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