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PAPER

Systematic Review of Digital Tools' Impact on Primary and Secondary Education Outcomes

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ABSTRACT

The systematic review investigates the impact of digital tools on learning outcomes in primary and secondary education. The study synthesizes research published between 2018 and 2023, employing a rigorous methodology that includes a comprehensive literature search across four academic databases, selecting 31 relevant studies through a dual-review process based on strict inclusion and exclusion criteria. The methodology focused on empirical studies examining the direct effects of digital tools on pedagogical practices and student achievement. The analysis revealed a significant positive impact of digital tools on student engagement, conceptual understanding, and academic performance across various subjects and educational levels. Key findings indicate that effective technology integration requires access to digital resources, targeted professional development for educators, infrastructural advancements, and supportive policy frameworks. The research identified challenges such as disparities in technology access and the slow pace of digital skills acquisition. This study contributes to the existing body of knowledge by providing a comprehensive overview of digital tool integration in education, highlighting its potential and the obstacles to its practical use. The findings advocate for a balanced and strategic approach to incorporating technology into educational settings, paving the way for future advancements in educational technology.

KEYWORDS

digital tools in education, technology-enhanced learning (TEL), educational technology integration, primary and secondary schools

1 INTRODUCTION

The rapid advancement of digital technology has significantly influenced educational settings, introducing a wide array of tools and platforms designed to enhance learning experiences [1]. In primary and secondary educational settings, digital tools play a crucial role in personalizing education, fostering autonomy among learners, and assisting educators in managing and guiding learning activities more effectively. The strategic incorporation of digital technologies in education at these

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levels is an essential response to the evolving digital landscape, ensuring that teaching methodologies remain relevant and engaging [2]. Central to the integration of digital tools in education is the Technological Pedagogical Content Knowledge (TPCK) framework [3]. This framework emphasizes the interdependence of technology, pedagogy, and content knowledge, advocating for an integrated approach to teaching that enhances learning outcomes. The TPCK framework posits that effective use of technology in education requires teachers to understand the content deeply and apply pedagogical strategies that leverage technology to enrich learning experiences [4].

Digital technologies have ushered in a shift towards more interactive and student-centered learning models. By incorporating digital tools into the curriculum, educators encourage students to engage in collaborative projects and knowledge exploration, fostering an environment where learning is both dynamic and participatory [5]. Professional development in equipping teachers with the skills necessary for effective technology integration is critical [6]. Research emphasizes technology's role in promoting engagement, personalizing learning, and improving academic performance. Technology supports learning by providing access to resources, enhancing skill development, and motivating learners [7]. TEL is particularly relevant in the formative years of education.

Strategic use of digital technology positively impacts educational outcomes [8]. Moderate engagement with educational technology improves test scores [9]. Moreover, a comprehensive analysis within Bangladesh demonstrated that technology has a medium effect on enhancing school quality, pointing to the significant role of digital tools in supporting teacher efficacy and improving educational environments in primary and secondary schools [10].

Integrating digital tools in primary and secondary education is an area of significant scholarly interest. Several systematic reviews and meta-analyses have aimed to evaluate the effectiveness of these tools on learning outcomes. However, many of these reviews present limitations in their focus or methodology. For instance, a systematic literature review exploring digital game-based learning outcomes for students aged 6 to 18 examined 26 articles and highlighted the potential benefits of digital games for language acquisition [11]. Another analyzed mobile learning in science and mathematics education within secondary schools [12]. Another systematic review focused on gamification in e-learning for young learners [13].

The review assessed the effects of e-books on students' mathematics achievement but primarily focused on specific interventions [14]. Although it employed a meta-analysis, its narrow focus on e-books does not encompass the broader array of digital tools that this study addresses. A meta-analysis on the effectiveness of digital-based interventions for children with mathematical learning difficulties was limited in scope as it focuses solely on interventions targeting mathematical skills, excluding other areas of learning impacted by digital tools [15]. Lastly, the characteristics of productive peer collaborative problem-solving in educational contexts through a qualitative systematic review examined collaboration's social and cognitive aspects but did not present quantitative outcomes or focus on digital tools specifically, making it less applicable to the current investigation of digital platform efficacy [16].

The existing reviews focus narrowly on specific types of tools such as augmented reality (AR), e-books, or gamification. Although these studies provide valuable insights, they partially assess the wide range of digital technologies available in educational settings. Moreover, many reviews are qualitative, needing more rigorous, quantitative evaluations of the effects of these tools on learning outcomes.

This review addresses these limitations by synthesizing findings from 31 empirical studies, each of which explores the impact of digital tools on primary and secondary education. Unlike previous studies, this review includes a broader spectrum of educational technologies and evaluates their effectiveness across different subject areas and contexts. By focusing on diverse tools and learning environments, this study offers a more holistic understanding of how digital tools influence student engagement, academic performance, and educational practices. We examine the overall effect size of digital tools on learning outcomes while considering key mediating variables such as study period and subject area. This comprehensive approach offers actionable insights for educators and institutions aiming to enhance learning through digital platforms.

2 METHODOLOGY

Table 1. Search queries used on various databases

Keywords	Database	Date	Articles
"digital tools," "primary education," "secondary education," "teaching methodologies," "learning outcomes,"	Google Scholar	30/03/2024	139
("digital tools" OR "educational technology") AND ("learning outcomes" OR "teaching methodologies") AND ("primary education" OR "secondary education")	JSTOR	30/03/2024	23
("digital tools" OR "educational technology") AND ("learning outcomes" OR "cognitive development" OR "student engagement") AND ("primary school" OR "secondary school") AND ("2018"[Date – Publication]: "2023"[Date – Publication])	Science Direct	30/03/2024	14
("digital tools" OR "educational technology") AND ("learning outcomes" OR "cognitive development" OR "student engagement") AND ("primary education" OR "secondary education") AND ("2018"[Date – Publication]: "2023"[Date – Publication])	Pub Med	30/03/2024	0

This systematic review examines the influence of digital tools on educational practices within primary and secondary school settings. Grounded in Piaget's stages of cognitive development, the investigation postulates that digital tools offer significant potential to enhance multimodal engagement and, subsequently, teaching practices within these educational levels [17], [18]. A comprehensive literature search strategy examined publications from 2018 to 2023 across five prominent academic databases. The selection of keywords and database-specific terms was strategic to encompass a wide array of studies on the subject matter (refer to Table 1 for search strategy details).

The initial search identified 176 pertinent records. Following the PRISMA guidelines, these records underwent a meticulous screening process to evaluate their relevance based on title and abstract, using Zotero for effective duplicate management [19]. This stage resulted in 84 articles deemed suitable for full review. The PRISMA guideline flowchart, which illustrates this process, is depicted in Figure 1 [19]. In order to uphold the study's methodological integrity, each article underwent a dual-review evaluation based on pre-established inclusion and exclusion criteria outlined in Table 2. An additional impartial reviewer resolved all disagreements. The scrutiny resulted in 80 articles aligned with the research focus.

Table 2. Inclusion and exclusion criteria

Category	Inclusion Parameter	Exclusion Parameter
Document Type	Peer-reviewed articles on digital education tools	Workshops, symposiums, grey literature
Technology Focus	Digital adoption in primary and secondary schools	Studies without digital integration
Educational Tools	Effectiveness of digital tools in education	Educator insights over classroom application
Impacts on Learners	Effects of digital platforms on engagement and achievement	Narratives limited to educator experiences
Methodological Approach	Empirical studies with robust methods	Anecdotal or descriptive studies
Publication Recency	Published from 2018 to 2023	Before 2018
Digital Tools' Effects	Trials measuring educational technology impacts	Speculative or theoretical reviews
Educational Context	Studies within schools on technology's impact	Non-formal environments
Study Design	Comparative studies on tech vs. traditional environments	Studies lacking comparative frameworks
Objective Learning Metrics	Quantifiable metrics for assessing outcomes	Studies using subjective assessments

A subsequent detailed full-text review distilled this number to 31 studies directly relevant to the objectives. The dual-reviewer strategy and comprehensive article assessment against stringent criteria ensured methodological rigor. The final selection included empirical studies that provided insights into digital tool integration and its effects on student learning outcomes. The meticulous process resulted in a robust body of research for in-depth analysis.

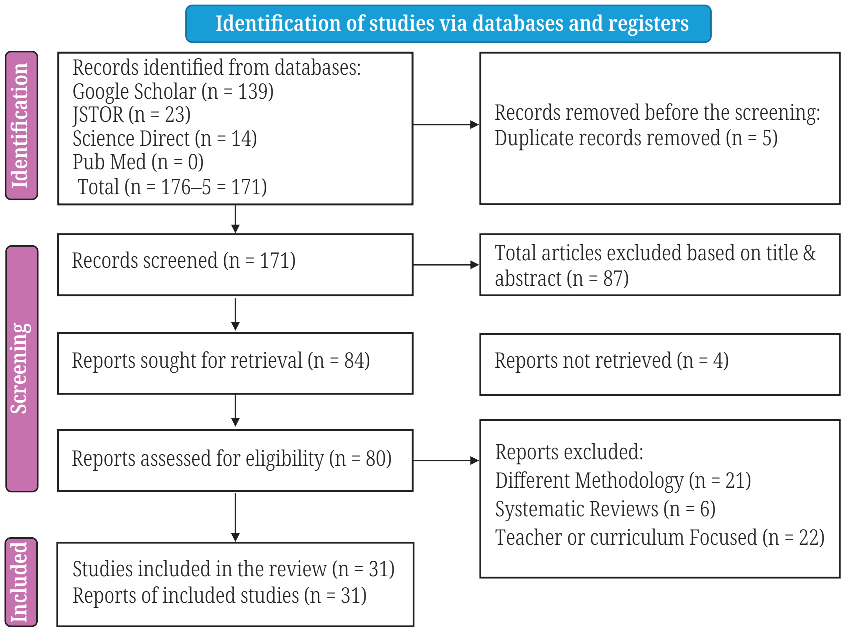

Fig. 1. PRISMA guideline flowchart [19]

The final step involved data extraction from the 31 studies that satisfied all criteria. Two researchers independently extracted data into specially designed excel worksheets to ensure consistency and rigor in data collection. The extracted data included types and functions of digital tools, methods of technology integration, and their impacts on student learning outcomes, among other relevant variables. The synthesized data was tabulated (refer to Table 3). The data extraction formed the foundation for a collaborative writing process, which integrated the findings to draw comprehensive conclusions on the role of digital tools in primary and secondary education.

The choice to use Google Scholar as a source for this review was made strategically due to its broad coverage across disciplines. Educational technology research is interdisciplinary and often published in various journals that are often not indexed in specialized databases, making Google Scholar a more suitable choice for comprehensive literature retrieval. Additionally, by sorting the search results by date, this review aimed to mitigate potential biases towards older or more frequently cited studies, ensuring the inclusion of the most recent and up-to-date research.

The review deliberately excluded terms such as "K-12" or "TEL" TEL to maintain a broader scope. "K-12" is commonly used in North American contexts, and its usage would have restricted research to specific educational systems, excluding relevant international studies. Similarly, although "TEL" is a widely recognized term, its use could have narrowed the search to studies specifically labeled under that terminology, potentially missing research employing different descriptors for educational technology. By opting for more general keywords, this review aimed to capture a diverse range of digital tools and interventions across different educational contexts to offer a global perspective.

Furthermore, this review did not employ snowballing, as the initial search resulted in many studies. The researchers did not search references from identified articles to find additional relevant studies to maintain a manageable scope. Prioritizing the studies identified through the primary search allowed for a more focused analysis without diluting the review with excessive literature. The broad search in Google Scholar captured critical foundational and contemporary studies, which reduced the need for secondary search methods such as snowballing. The chosen strategy facilitated a comprehensive and targeted review, ensuring a balanced analysis in both breadth and depth.

Table 3. Summary of studies included in the review

Source	Methodology	Educational Technology	Outcome	Country
[20]	QE	Technology-enhanced learning environment (Web-based Inquiry Science Environment)	PE	China
[21]	RCT	Adaptive web-based program (Reading Plus)	PE	United States
[22]	E	Mobile Application (Ipads)	PE	United States
[23]	QE	Online platform	PE	Malaysia
[24]	QE	Game-based learning platform (Kahoot) and online learning platform (Pin Up)	PE	Malaysia
[25]	QE	Gamification and Game-based Student Response System (GSRS)	PE	Malaysia
[26]	QE	Computer programs and tools	PE	North Macedonia

(Continued)

Table 3. Summary of studies included in the review *(Continued)*

Source	Methodology	Educational Technology	Outcome	Country
[27]	E	Whiteboard animations	PE	Germany
[28]	E	Game-based learning platform (New Oriental Fun Vocabulary and Kingsoft Vocabulary)	PE	China
[29]	QE	Augmented Reality (AR Solids)	PE	Brazil
[30]	QE	Digital escape room activities	NE	Taiwan
[31]	E	Tangible Interaction Technologies (CRISPEE)	PE	United States
[32]	E	Virtual Reality and Augmented Reality	PE	Cyprus
[33]	E	Augmented Reality	PE	Turkey
[34]	E	Augmented Reality	PE	Ecuador
[35]	QE	Augmented Reality	PE	Taiwan
[36]	QE	Game-Based Learning Environment (Misha and Kosha)	PE	Iran
[37]	QE	3D technology	ME	Austria and Australia
[38]	E	Computer Animations	PE	India
[39]	E	Augmented Reality	ME	China
[40]	QE	Augmented Reality (Problem-Based Learning)	PE	Turkey
[41]	RCT	Mobile Application (Tablet)	PE	Germany
[42]	RCT	Online platform (Socrative)	PE	The Netherlands
[43]	E	Computer Activities and Movie	PE	United States
[44]	RCT	Mobile Applications (Tablet computers)	PE	Germany
[45]	QE	Technology-enhanced learning environment (Interactive software and digital books)	PE	Kenya
[46]	E	Virtual Reality	PE	China
[47]	QE	Technology-enhanced learning environment (Interactive software-Gazelle)	ME	The Netherlands
[48]	RCT	Technology-enhanced learning environment (Lexia PowerUp Literacy program)	PE	United States
[49]	QE	Programming Environment (Lego EV3 robotics sets vs. Scratch Software)	PE	Turkey
[50]	E	Programming Environment (Paper-based vs. Scratch Software)	PE	France

Notes: E = Experimental Design; QE = Quasi-Experimental Design; RCT = Randomized Controlled Trial; PE = Positive Effect; ME = Mixed Effect; NE = Negative Effect.

3 RESULTS

This systematic review methodically assessed 31 studies to ascertain the influence of digital tools on educational outcomes in primary and secondary settings.

The analysis considered a range of factors, including the type of technology employed, the geographic origin of the research, the methodological approach, and the specific outcomes related to student learning.

3.1 Geographical distribution of studies

Figure 2 illuminates the international engagement in educational technology research. The chart indicates that the United States, with five studies, is at the forefront of educational technology research. Four studies originating from China highlight its substantial role. Germany, Malaysia, and Turkey each present three studies. Taiwan and the Netherlands have also shown notable activity by contributing two studies. Moreover, several countries contribute one study each.

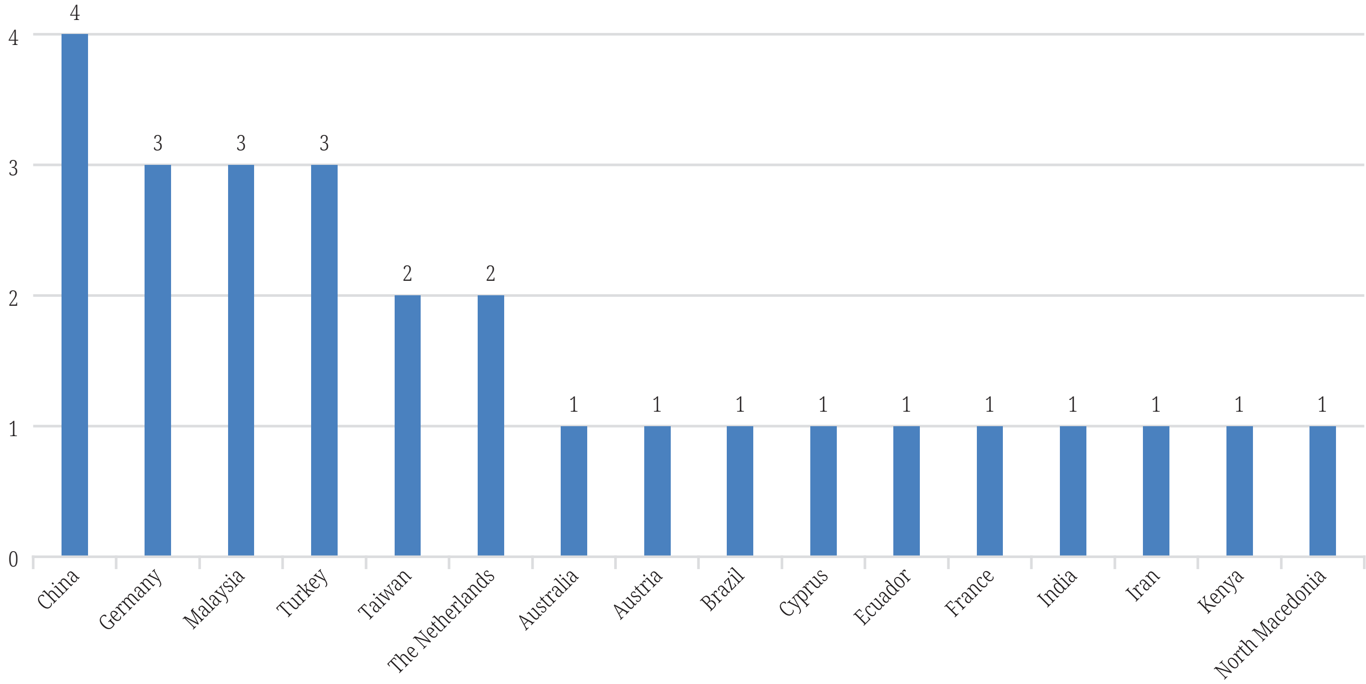

Fig. 2. Studies investigating educational technology interventions in each country

3.2 Temporal distribution of studies

Figure 3 delineates the trend in scholarly research on the role of digital tools in enhancing educational practices from primary through secondary levels. Four studies in 2018 indicated the initial surge in research output. There were eleven studies in 2019. The momentum continued in 2020 with 10 studies. However, the landscape shifted in the subsequent years, with a noticeable decrease to two studies each in 2021, 2022, and 2023.

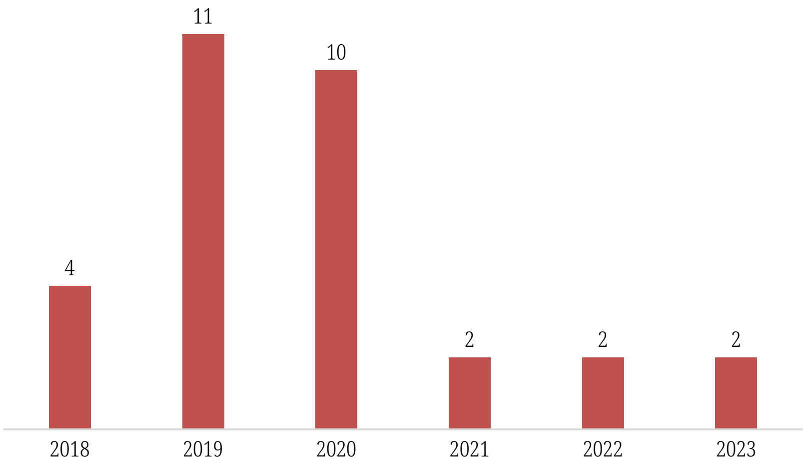

Fig. 3. Number of studies published in each year

3.3 Methodological comparison of studies

Figure 4 delineates the number of studies utilizing various methodologies. Five studies were randomized controlled trials (RCTs), 12 were experimental, and 14 employed quasi-experimental designs.

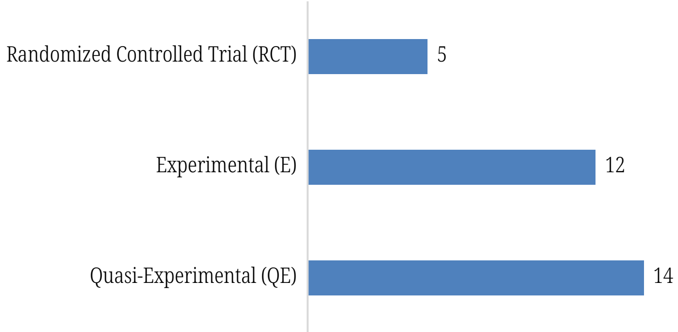

Fig. 4. Number of studies using a particular methodology

3.4 Measurement of effects across studies

The systematic review of 31 studies indicates a predominantly positive influence on learning outcomes. Twenty-seven studies reported positive effects. Figure 5 shows the measurement of effects across studies, illustrating the distribution of these outcomes. Three studies identified mixed effects, and one study demonstrated adverse effects.

Fig. 5. Measurement of effects across studies

3.5 Sample population and effect sizes across studies

The studies reviewed can be organized thematically based on the measured outcomes: learning gains, cognitive engagement and motivation, reading comprehension, and problem-solving and algorithm design. Several studies focused on learning gains across various subjects. For example, 125 middle school students were assessed on their understanding of photosynthesis, reporting effect sizes of 0.54 for typical items and 0.045 for KI items, measured through pre-tests, post-tests, and log data [20]. In a study with 100 fourth- and fifth-grade students learning the Chinese language, multiple-choice tests and surveys were used to assess E-flashcard performance, reporting an effect size of 1.44 [22]. Vocabulary learning in 96 third-grade students was measured through vocabulary scales and semi-structured interviews, yielding a mean score increase of 13.43 points [28]. Similarly, 40 fourth-grade students engaged in performance and problem-solving tests showed a mean score of 88.73 for the experimental group versus 87.18 for the control group [30]. A study measured learning effectiveness for virtual reality (VR) and AR activities in 30 primary school students with effect sizes of 1.5 for VR and 1.3 for augmented reality [32].

Several studies measured the impact of different interventions on cognitive engagement and motivation. In 133 secondary school students, motivation and retention were assessed through surveys, reporting effect sizes of $\eta^2 = 0.18$ for mental load and $\eta^2 = 0.09$ for narratives [27]. A study of 401 seventh- and eighth-grade students assessed climate literacy, with an R^2 of 0.014 and an increase of 5.16 points in climate literacy scores between pre- and post-tests [36]. Measurement of motivation, group efficacy, and critical thinking in 111 fifth-grade students gave effect sizes reported as 0.42 for project performance, 0.56 for motivation, 0.49 for critical thinking, and 0.46 for group efficacy [38]. Cognitive engagement and academic effort were evaluated in a study of 1,363 seventh- and eighth-grade students using tablet integration, reporting beta coefficients of $\beta = 0.113$ for cognitive engagement and $\beta = 0.172$ for academic effort [43].

Several studies focused on reading comprehension and related skills. In a study with 426 fourth- and fifth-grade students, standardized tests and eye movement recordings were used to assess reading comprehension and vocabulary, with effect sizes of 0.42 for reading rate and 0.22 for achievement [21]. Another study measured reading comprehension gains of 1,672 students from grades 1-3 through reading comprehension tests, with effect sizes ranging from Cohen's d 0.19 to 1.46 [44]. For 174 seventh-grade students, reading comprehension evaluations showed effect sizes of 0.08 for hints and 0.02 for overall comprehension [46]. Similarly, a study of 55 middle school students assessed reading proficiency through tests, reporting an effect size of $d = 0.36$ for the Power Up intervention [47].

Problem-solving and algorithm design were also key areas of focus. A study with 60 sixth-grade students reported that 94% of students in Class A and 75% in Class B correctly answered questions related to geometric solids during AR quizzes and engagement surveys [29]. In another study with 8 and 38 sixth-grade students, F-statistics of 9.97 for algorithm design and 9.48 for data processing confirmed the effectiveness of Lego-based interventions [48]. A study with 217 primary school students also measured algorithm problem-solving through surveys, reporting effect sizes of $d = 0.56$ for loops, $d = 0.41$ for conditions, and $d = 1.04$ for variables [49].

These studies demonstrate varied results in learning gains, engagement, reading comprehension, and problem-solving abilities across different educational contexts. Sample sizes range from small to large, and effect sizes reflect a range of impacts depending on the intervention. Table 4 contains the sample sizes and measured outcomes.

Table 4. Summary of research studies on the impact of digital tools on learning outcomes across various subjects and educational levels

Source	Sample Size	Subjects	Measurement Method	Measured Value	Type of Value	Outcome Type
[20]	125 (middle school students)	Photosynthesis	Pre-tests, post-tests, log data	0.54 (typical items), 0.045 (KI items)	Effect size (Cohen's d)	Learning Gains
[21]	426 (4th and 5th grade)	Reading comprehension, vocabulary	Standardized tests, eye movement recordings	0.42 (reading rate), 0.22 (achievement)	Effect size (Cohen's d)	Reading Rate and Achievement
[22]	100 (4th and 5th grade)	Chinese language	Multiple-choice tests, surveys	1.44 (E-flashcards)	Effect size (Cohen's d)	Learning Gains
[23]	42 (4th Grade)	Paragraph writing skills	Tests and questionnaires	Increase from 3.8 to 4.9 (School A), 2.1 to 3.1 (School B)	Mean score increase	Writing Skills
[24]	29 (7th grade) 27 (9th grade)	ESL writing skills	Pre-tests, post-tests	Increase of 2.53 (Form 1), 1.35 (Form 3)	Mean score increase	Writing Skills
[25]	35 (2nd-3rd grade)	English irregular verbs	Quizzes	Increase from 5.57 to 17.29	Mean score increase	Memory Retention (Gamification)
[26]	526 (secondary school)	Mathematics (geometry)	Pre- and post-test, surveys	Increase of 11.36	Mean score increase	Mathematics Skills
[27]	133 (secondary school)	Motivation, retention, transfer	Intrinsic motivation, retention surveys	$\eta^2 = 0.18$ (mental load), $\eta^2 = 0.09$ (narratives)	Effect size (Eta squared)	Cognitive Load and Retention
[28]	96 (3rd grade)	Vocabulary learning	Vocabulary scale, semi-structured interviews	Increase of 13.43 points	Mean score increase	Vocabulary Learning
[29]	60 (6th grade)	Geometry solids	AR quizzes, engagement surveys	94% (Class A) and 75% (Class B) correct answers	Percentage (Correct Answers)	Engagement and understanding
[30]	40 (4th grade)	Science, problem-solving	Performance tests, problem-solving tests	88.73 (experimental) vs. 87.18 (control)	Mean score	Problem-Solving
[31]	82 (aged 4–9)	Bioluminescence gene coding	Interaction analysis via video data	69% (understood in 5 mins), 92% (understood in 10 mins)	Percentage (Correct Understanding)	Conceptual Understanding
[32]	30 (primary school)	VR, AR activities	Pre-tests, post-tests, Likert scale surveys	1.5 (VR), 1.3 (AR)	Effect size (Mean difference)	Learning Effectiveness (VR, AR)
[33]	460 (8th grade)	3D thinking skills	Pre-tests, post-tests	0.55 (control), 1.23 (experimental)	Test score improvement	3D Thinking Skills
[34]	29 (3rd grade)	Written learning outcomes	Paired t-tests	1.63 points (low-performance group), 0.59 (high-performance)	Mean score increase	Written Learning Outcomes
[35]	137 (6th Grade)	Math anxiety, geometry	Pre-tests, post-tests, anxiety scale	0.37 (algebra), 0.21 (geometry)	Effect size (Cohen's d)	Math Anxiety and Performance
[36]	60 (1st grade)	Achievement motivation	Pre- and post-tests, motivation surveys	$\eta^2 = 0.727$	Effect size (Eta squared)	Achievement Motivation (Game-Based Learning)

(Continued)

Table 4. Summary of research studies on the impact of digital tools on learning outcomes across various subjects and educational levels *(Continued)*

Source	Sample Size	Subjects	Measurement Method	Measured Value	Type of Value	Outcome Type
[37]	401 (7th-8th grade)	Climate literacy	Climate literacy questionnaires	$R^2 = 0.014$, Increase of 5.16 points	R-squared, Mean score increase	Climate Literacy
[38]	544 (2nd, 4th, 6th grades)	Multiple subjects (animated instruction)	Pre-tests, post-tests	Increase from 7.28 to 11.25	Mean score increase	Learning Outcomes (Animated Instruction)
[39]	111 (5th grade)	Motivation, group efficacy	Questionnaires	0.42 (project performance), 0.56 (motivation), 0.49 (critical thinking), 0.46 (group efficacy)	Effect size (Cohen's d)	Motivation, Critical Thinking, Group Efficacy
[40]	91 (7th grade)	Physics learning	Pre- and post-tests, ANCOVA	Improvement: 14.74 (EG-1), decline for EG-2 (–5.33), CG (–10.76)	Mean score increase	Attitude Toward Physics
[41]	262 (secondary school)	Physics, cognitive load	Multilevel regression	$\eta^2 = 0.078$	Effect size (Eta squared)	Cognitive Load
[42]	633 (secondary school)	Higher-order thinking (physics)	Socrative feedback	0.4 standard deviations	Effect size (Standard deviations)	Metacognition and Motivation
[43]	7774 (Grades 5-8)	Mathematical pattern manipulation	Surveys	52.6% (computer game condition), 42.6% (mindset modules)	Percentage (High Engagement)	Engagement
[44]	1363 (7th-8th grade)	Cognitive engagement, ICT literacy	Tablet use surveys	$\beta = 0.113$ (cognitive engagement), $\beta = 0.172$ (academic effort)	Beta coefficient	Cognitive Engagement, Academic Effort
[45]	1672 (Grades 1-3)	Reading comprehension	Reading comprehension tests	Effect sizes: Cohen's d 0.19 to 1.46	Effect size (Cohen's d)	Reading Comprehension
[46]	150 (2nd-3rd grade)	Pedestrian safety (VR learning)	Knowledge tests, behavior observation	$\eta^2 = 0.10$ (total score), $\eta^2 = 0.08$ (interpretation), $\eta^2 =$ 0.07 (decision-making)	Effect size (Eta squared)	Knowledge, Decision-Making
[47]	174 (7th grade)	Reading comprehension	Reading comprehension tests	0.08 (hints), 0.02 (overall)	Effect size (Eta squared)	Reading Comprehension
[48]	55 (middle school students)	Reading proficiency	Reading proficiency tests	$d = 0.36$	Effect size (Cohen's d)	Reading Proficiency
[49]	8 and 38 (6th grade)	Algorithm design	Pre-tests, post-tests	$F = 9.97$ (algorithm design), $F = 9.48$ (data processing)	F-statistic	Algorithm Design, Data Processing
[50]	217 (primary school)	Algorithm problem-solving	Surveys	$d = 0.56$ (loops), $d = 0.41$ (conditions), $d = 1.04$ (variables)	Effect size (Cohen's d)	Programming Concepts

4 DISCUSSION

This systematic review offers a comprehensive assessment of the diverse impacts of digital tools in primary and secondary education. Most studies report positive learning gains. The broader benefits of digital tools extend beyond academic performance and offer unique learning scenarios and opportunities for sustained engagement. However, the review highlights the mixed outcomes of TEL implementations and underscores the need for careful, context-specific deployment.

4.1 Categorization and differentiation of digital tools in educational settings

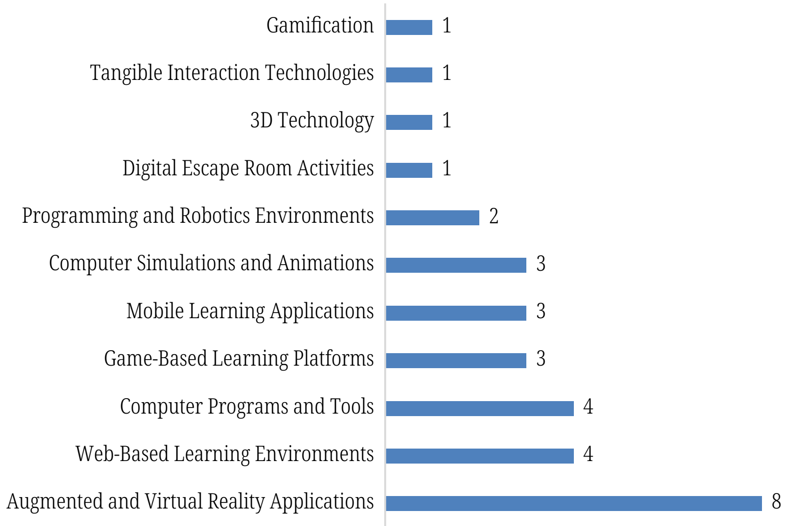

Fig. 6. Category of educational technology used across studies

The review categorizes digital tools into several key types. Figure 6 depicts the categorization of technologies found in the studies. AR and VR Applications represent immersive tools that create interactive learning environments by blending digital content with real-world or virtual spaces. These technologies are especially effective in subjects requiring high levels of visualization. By offering learners hands-on experiences in virtual settings, AR and VR can enhance understanding of complex concepts that are difficult to grasp through traditional methods. Eight studies explore augmented and VR applications [29], [32], [33], [34], [35], [39], [40], [46]. These studies showcase the immersive learning experiences offered by AR and VR technologies, which have been particularly effective in fields requiring interactive 3D models and simulations. The immersive nature of these tools significantly enhances engagement and understanding, offering innovative ways to explore complex concepts. AR applications can significantly enhance the understanding of geometric solids, with a 75% accuracy rate among students in identifying these shapes [29]. This capacity for spatial understanding through VR or AR platforms supports the assertions of the Constructivist Learning Theory regarding personalized learning experiences and reduced cognitive load [51].

Game-Based Learning Platforms focus on using fully developed games designed for educational purposes. These platforms integrate learning objectives into the gameplay, allowing students to acquire knowledge and skills directly from participating in the game. Students learn vocabulary, problem-solving, or coding through interactive gaming environments. Game-based learning centers on using actual games where learning emerges from gameplay. Three studies feature game-based learning [24], [28], [36]. These platforms utilize game mechanics to increase student engagement and motivation, illustrating the potential of gamified learning environments to enhance educational outcomes through interactive and fun learning experiences.

Gamification involves adding game-like elements such as points, badges, or leaderboards to traditional learning activities to motivate and engage students. Unlike game-based learning, gamification does not transform the learning activity into a game but enhances it with extrinsic motivators. The game-based student response system (GSRS) uses 'Kahoot!' to enhance the learning and memory retention of English irregular verbs among young students [25]. The platform integrates gamification elements, such as interactive quizzes, leaderboards, and point systems, to make learning grammar more engaging and effective for students.

Web-based learning environments provide online platforms where educational resources are available, often including interactive exercises, assessments, and collaborative tools. Four studies explore web-based learning environments [20], [21], [23], [42]. These environments leverage the accessibility of web-based platforms to offer interactive learning modules, demonstrating how browser-based technologies can facilitate effective learning outside traditional classroom settings. Online platforms improve participants' digital skills [52]. Other research has shown that interactive web platforms stimulate interest and enhance conceptual understanding through visualization [53].

Computer programs and tools encompass software and applications that assist in specific learning tasks, such as data analysis, writing, or design. Four studies use computer programs and tools, including software applications designed for specific educational purposes [26], [45], [47], [48]. These tools support a variety of academic tasks, from facilitating learning activities to enhancing student engagement and understanding.

Mobile learning applications leverage the portability and accessibility of smartphones and tablets to offer educational content and activities. Three studies examine mobile learning applications [22], [41], and [44]. These applications highlight the growing trend of utilizing mobile devices for learning, providing flexible and accessible educational resources that students can engage with from anywhere. These applications are handy for vocabulary acquisition, mathematical problem-solving, and interactive exercises, enabling learning outside the traditional classroom environment.

Computer simulations and animations allow students to engage with dynamic representations of real-world processes and phenomena. By simulating scientific experiments, mathematical models, or historical events, these tools help learners understand abstract concepts in an engaging and visually stimulating manner. Computer simulations and animations are the focus of three studies [38], [43], [53]. These technologies utilize dynamic visuals and interactive simulations to make complex concepts more understandable, offering a powerful tool for enhancing learning in various subject areas.

Programming and robotics environments introduce students to coding, robotics, and computational thinking. These tools are increasingly integrated into curricula to develop problem-solving skills and technological literacy, essential competencies in the modern digital economy. Two studies discuss programming and robotics environments [49], [50]. These environments provide platforms for developing essential programming and computational thinking skills, emphasizing the importance of hands-on learning experiences in fostering technological literacy.

Digital escape room activities provide an interactive, problem-solving experience in which learners must collaborate and use critical thinking to solve puzzles and unlock progress. These activities encourage teamwork, communication, and application of subject knowledge in an engaging and often competitive format.

3D technology uses three-dimensional modeling and visualization tools to enhance spatial understanding and design skills. This technology is valuable in engineering, architecture, and medicine, where spatial reasoning and precision are critical. One study showcases digital escape room activities [30], and another highlights 3D technology [37]. Each offers unique approaches to engaging students. The former encourages interactive problem-solving and critical thinking through gamified challenges, while the latter enhances spatial understanding through hands-on learning experiences.

Tangible interaction technologies involve tangible, physical tools designed to make abstract concepts, such as genetics, more accessible for young children. The CRISPEE technology allows children to interact with tangible representations of genes, making complex STEM topics, such as bioengineering and bio-design, more comprehensible for early childhood learners [31]. This evolution of interactive methodologies resonates with Constructivist Learning Theory, which suggests that learners construct knowledge through experiences and reflections within their environment [54].

The systematic organization of these technologies into categories elucidates the diverse and significant impact of digital tools on educational outcomes. As educational practices continue to evolve, these technologies play a pivotal role in shaping innovative learning processes, engaging diverse student populations, and facilitating immersive and practical learning experiences. This analysis underscores the broadening scope of educational technology and its demonstrable benefits for pedagogical techniques and learning outcomes across various instructional contexts.

4.2 Geographic distribution

This geographical diversity of 32 studies from 17 different countries validates a widespread, international resolve to capitalize on technological advancements for educational enhancement. The collective endeavor across nations to integrate technology into education highlights a shared vision to augment teaching and learning experiences. The range of contributions from these countries showcases a unified drive to confront universal challenges within educational technology, seeking to employ such interventions to improve educational outcomes globally. The geographical distribution of studies reflects the dynamic, encompassing nature of educational technology research, transcending borders and uniting a diverse assembly of nations in a common scholarly pursuit.

4.3 Temporal distribution

The change in research priorities after 2020 likely mirrors the scholarly community's response to the unprecedented challenges posed by the COVID-19 pandemic, as the focus pivots towards addressing immediate issues related to the sudden transition to online learning environments [55]. The reduced frequency of studies investigating digital tool integration during these years suggests a broader reallocation of research efforts to address emergent educational hurdles, including equitable access to technology and the effectiveness of virtual teaching methodologies. Despite this downward trend in the specific research area of digital tool integration, the consistent publication of relevant studies through these years reflects a steadfast pursuit to enhance educational methods via technological innovations.

This ongoing research activity evidences the adaptability and resilience of educational scholarship, which remains responsive to new challenges while continuing to evolve within the educational landscape.

4.4 Methodological distribution

The collection of RCTs and experimental and quasi-experimental designs reinforces the review's conclusions with a substantial empirical foundation. It underscores the comprehensive nature of the review, reflecting the multifaceted character of educational technology research. Doing so lays a solid groundwork for future investigations, enabling researchers to build upon robust, methodologically validated evidence and to continue the scholarly discourse on integrating digital tools in educational practice.

4.5 Effects of digital tools across studies

The discussion of the results reveals several essential insights into the effectiveness of TEL across various educational settings. One consistent finding is the positive impact of TEL on learning gains, particularly in studies with larger sample sizes. The substantial effect sizes reported in several studies suggest that digital interventions can significantly enhance students' conceptual understanding and subject-specific knowledge. For example, the large effect sizes observed in photosynthesis and reading comprehension studies indicate that TEL can facilitate deeper learning when appropriately integrated into the curriculum [20], [21]. These findings align with previous research on the efficacy of digital tools in improving both knowledge retention and academic performance, mainly when the interventions target specific learning objectives [56].

However, the review also highlights the complexity of TEL's impact, as not all interventions resulted in improved academic performance. While digital tools often lead to increased motivation and engagement, these benefits do not always translate into measurable learning gains. Although Digital Escape Room (DER) increased student motivation, it did not significantly improve learning performance [30]. The DER study suggests that although motivation is crucial in learning, it is insufficient to ensure academic success. Educators must ensure that digital interventions are engaging and designed to promote meaningful cognitive development and knowledge acquisition [57].

The review highlights novelty effects, where the initial enthusiasm for new technologies can lead to short-term engagement. The results improve if the tools are effectively integrated into the learning process [28]. In another study, progressive drawings and narratives initially reduced cognitive load and improved retention, but these effects were not long-term [27]. Maintaining engagement requires dynamic adaptation to prevent the effects from wearing off too quickly [41].

The mixed outcomes observed in some studies also underscore the importance of context-specific applications of TEL. For instance, while certain interventions led to significant improvements in areas such as mathematics and vocabulary learning, other studies reported minimal or no gains in problem-solving or science skills [29], [30]. The mixed results suggest that the effectiveness of TEL may vary depending on the subject matter, the complexity of the content, and the learners' familiarity with digital tools [25].

Additionally, statistical power plays a crucial role in evaluating the reliability of the findings across the studies reviewed. Studies with larger sample sizes reported more robust effect sizes, providing more substantial evidence for the positive impact of TEL [21], [26]. For example, a study with a sample of 526 students demonstrated significant learning gains in geometry, bolstering the claim that TEL interventions can lead to measurable improvements in academic performance [26]. Conversely, studies with smaller sample sizes present limitations in their generalizability due to reduced statistical power [23], [24]. Although these studies reported positive learning gains, their smaller sample sizes require cautious interpretation.

Another key finding is the influence of TEL on non-academic outcomes, such as motivation and cognitive load. Several studies reported moderate to large effect sizes for motivational gains, particularly in settings where TEL interventions enhance student engagement [27], [36]. However, the novelty effect may contribute to these initial increases in motivation, and further research is needed to assess the long-term sustainability of these effects [41]. Motivation fosters engagement with course material. However, motivation must pair with instructional strategies that promote deeper learning to achieve lasting academic gains [56].

Technology-enhanced learning offers additional advantages, such as enabling unique learning scenarios that are not feasible in traditional educational settings. AR and VR tools allowed students to interact with geometric solids in ways that significantly enhanced their spatial understanding [29]. These immersive technologies enable hands-on, experiential learning opportunities that deepen conceptual comprehension, particularly in subjects requiring visualization and manipulation of abstract objects. Such experiences are difficult to replicate in traditional classroom environments, highlighting the broader potential of TEL beyond knowledge acquisition.

Another aspect to consider is the risk of "gaming the system," particularly in digital interventions that include features such as hints and scaffolding. While hints can support students in navigating complex tasks, there is potential for students to misuse these tools by relying on them to bypass meaningful engagement with the material. One study observed that while hints improved comprehension performance in reading tasks, they also led to some students using the hints strategically to complete tasks without fully understanding the content [47]. This behavior can undermine the learning process, as students may focus on completing tasks quickly rather than developing greater cognitive skills.

Despite these challenges, TEL's capacity to create personalized and adaptive learning experiences remains one of its most significant advantages. Programs such as Power Up demonstrate TEL's potential to tailor content to individual learner needs, especially for struggling students [48]. In this case, the program successfully improved reading proficiency among middle school students by adapting to each learner's performance level. This personalized approach is crucial for addressing diverse student needs, especially in large, heterogeneous classrooms.

The variability in outcomes across different subject areas indicates the importance of aligning TEL tools with specific pedagogical goals. Certain interventions, such as those focusing on vocabulary learning and mathematics, showed clear learning gains [26], [28]. Other studies reported increased motivation and problem-solving skills but no significant improvements in academic performance [30]. One study showed that game-based learning significantly boosted students' motivation, even if the impact on academic performance was more modest [36].

Many reviewed studies focused on short-term outcomes, leaving questions about the sustainability of TEL's impact on academic performance and student engagement. For instance, one study observed immediate positive effects on motivation and cognitive load [27]. However, the long-term effects are inconclusive. As TEL tools become more integrated into education systems, understanding their long-term influence on learning outcomes and student development will be critical.

5 LIMITATIONS

The systematic review focused on evaluating the impact of digital tools in primary and secondary education and is subject to several limitations that may influence the comprehensiveness and applicability of its findings. Notably, the methodologies across the studies analyzed were not uniform, introducing variability that could affect the aggregation and interpretation of results. This methodological diversity, encompassing different digital tools and educational interventions, challenges drawing broad, generalizable conclusions about the overall efficacy of TEL. Further complicating the matter is the range of geographic and demographic contexts represented in the studies, which may limit the generalizability of the findings to other settings and cultures.

The diversity necessitates caution when applying the review's insights across different educational systems. Moreover, given the rapid pace of technological innovation, the tools and platforms investigated may soon become outdated. This rapid evolution challenges the review's long-term relevance, as newer technologies could significantly alter the educational landscape. The review also identifies a gap in the literature regarding the negative or inconclusive impacts of TEL, suggesting a potential publication bias or an underrepresentation of such studies. The gap highlights the need for further research that rigorously explores less favorable outcomes and delineates the conditions under which TEL interventions are most effective. Addressing these limitations in future studies is crucial for enhancing the understanding of digital tools' roles in education and optimizing TEL strategies to meet evolving educational needs and contexts.

6 CONCLUSION

This systematic review has demonstrated the transformative potential of digital tools in primary and secondary education, particularly in fostering engagement, enhancing motivation, and improving learning outcomes. The findings reveal that successful integration of technology goes beyond mere access to digital resources—it requires strategic alignment with specific educational contexts, sustained application, and adaptability to meet the diverse needs of learners. Notably, tools such as AR and VR significantly improve spatial understanding, while adaptive learning technologies offer personalized learning experiences, addressing the varying proficiencies among students. However, the review also highlights challenges such as novelty effects, "gaming the system" behaviors, and the necessity of thoughtful TEL design to prevent superficial engagement with content. Moving forward, the key to effective technology integration lies in context-specific applications, continuous professional development for educators, and developing infrastructure and policies that support equitable access. These insights emphasize the importance of refining digital learning practices to create inclusive and engaging educational environments that can adapt to the rapid pace of technological advancement.

7 IMPLICATIONS

Instructional models such as TPCK and SAMR are necessary to assess the long-term benefits of technology integration and prepare educators for effective use [4], [6]. Educators require ongoing professional development to effectively use these technologies, while infrastructural investments are necessary to ensure equitable access. Equitable access is key. Investments in digital infrastructure ensure that all students have the necessary digital tools for learning [58]. Digital literacy requires investment in crucial infrastructure, policies promoting digital literacy, and professional development of educators [59]. ICT also enables personalized learning experiences [60]. The demonstrated success of personalized learning platforms such as the Power Up Literacy Program shows the potential of adaptive technologies to cater to individual student needs.

Additionally, long-term induction of tablets in the school curriculum provides sustainable results. These findings reinforce the importance of thoughtful, consistent, and well-supported application of TEL across educational systems to maximize its benefits. Student data and AI may be used under ethical guidelines to support educational goals. A collaborative approach among educational, governmental, and industrial stakeholders is essential to address the challenges of digital tool integration and foster a more inclusive educational ecosystem.

8 FUTURE RESEARCH

Future research should evaluate the long-term impacts of emerging digital technologies in diverse educational contexts, focusing on strategies to maintain engagement beyond the novelty phase and designing scaffolding systems that promote deep learning over task completion. Addressing the digital divide and providing professional development for educators using advanced digital tools will be critical to maximizing the benefits of technology in education. Expanding future reviews to include more specialized databases could capture a broader range of relevant studies. Longitudinal studies are necessary to assess the long-term benefits of technology integration.

9 AUTHOR CONTRIBUTIONS

All authors contributed to the article's concept, design, data collection, interpretation, writing, and critical revision. They also all approved the final version of the manuscript.

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11 DECLARATIONS

The authors state that they have no conflicts of interest.

12 DATA AVAILABILITY AND SHARING POLICY

All data pertinent to this study are included within this paper and sourced exclusively from publicly available literature, as detailed in the references.

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