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Comparative Analysis of the Impact of Digital Learning Tools on STEM Education Outcomes in Asian and European Classrooms

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ABSTRACT: *This study used a mixed methods approach, combining quantitative data from student test scores and participation surveys with qualitative insights from interviews with educators and students, to explore the impact of digital learning tools on STEM education outcomes in Asian and European classrooms, with a focus on their effectiveness in enhancing student engagement and academic performance. The findings reveal that the integration of digital tools significantly improves both engagement and learning outcomes. Specifically, students demonstrated a greater than 4.3% increase in test scores across various STEM subjects, and their engagement levels rose by 26%. However, the effective implementation of digital learning tools faces challenges related to regional differences in access to digital infrastructure and the lack of continuous teacher training and technical support. To maximize the potential of these tools, this study emphasizes the need for equitable access to technology, continuous teacher training, and the adoption of blended learning models to improve STEM educational outcomes.*

Keywords: Digital learning tools, STEM education, Student engagement, Technology integration, Teacher training

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INTRODUCTION

Digital learning tools transform education by enhancing accessibility, engagement, and personalized learning, particularly in STEM fields. Platforms such as online learning management systems (LMS) and interactive simulations improve the comprehension of complex concepts through real-time feedback and collaborative features, fostering 21st-century skills. Studies confirm that these tools increase student participation, knowledge retention, and STEM learning outcomes (Xu & Ouyang, 2022; Zawacki-Richter et al., 2020).

STEM education holds paramount importance worldwide because of its significant impact on national economies and technological advancement. In the era of rapid development of artificial intelligence technology, intelligent transformation in the field of education has gradually become a key driving force for improving teaching quality. Countries are increasingly focusing on STEM education to equip their students with the skills necessary to succeed in modern economies (Freeman et al., 2019; Jahani et al., 2024; Zou et al., 2025). This is particularly critical for international students, whose experiences with digital learning tools in STEM fields can significantly influence their academic success and cross-cultural adaptation (Aydin & Smith, 2023). Countries across Asia and Europe are adopting policies to strengthen their STEM education systems, recognizing that proficiency in these fields fosters innovation and economic growth. The emphasis on digital learning tools aligns with this goal by offering innovative approaches to teaching and learning that can meet the diverse needs of students (Eden et al., 2024).

Although an increasing number of people are using digital learning tools, the effectiveness of these tools in STEM education remains underexplored, particularly in comparative studies between regions. While several studies have examined the implementation of digital tools, significant gaps exist in understanding how their integration varies across cultural and educational contexts. For example, a meta-analysis highlighted the positive impact of digital game-based learning on STEM education outcomes (Wang et al., 2022) but did not address differences in regional implementation strategies or outcomes. This lack of regional focus limits the generalizability of the findings, especially across Asia and Europe (Timotheou et al., 2023). Similarly, the "STEAM Education in Europe: A Comparative Analysis Report" provides valuable insights into STEM practices within Europe but does not extend its analysis to comparative contexts involving Asian education systems (Haesen & Van, 2018). These gaps underscore the need for more comprehensive research to examine the differential integration and effectiveness of digital learning tools in STEM education across diverse cultural and educational settings. Furthermore, the impact of digital learning tools on student engagement and academic performance needs to be examined to ensure their effective deployment in STEM curricula. Addressing this gap can provide insights into optimizing digital tool usage to enhance STEM education outcomes globally.

This study aims to conduct a comparative analysis of the impact of digital learning tools on STEM education in Asian and European classrooms. The main purpose is to assess the impact of these tools on student engagement and academic performance across different education systems. Additionally, the study seeks to investigate how the integration of digital tools varies across these regions, taking into account cultural, technological, and infrastructural differences. By focusing on these aspects, this research provides a nuanced understanding of the role that digital learning tools play in enhancing STEM education outcomes in diverse settings (Zhao et al., 2022).

For educators, this study provides evidence-based strategies for optimizing digital tool integration in STEM curricula to enhance learner engagement and academic performance (Triplett, 2023). Policymakers benefit from the findings by gaining a clearer understanding of how to support schools and educational institutions in adopting these tools effectively. The comparative nature of the study, focusing on Asia and Europe, offers a broader perspective, which can inform global educational strategies. Finally, for future researchers, this study fills an important gap in the literature by highlighting regional differences and providing a framework for further exploration of digital learning tools in education (Momani et al., 2023).

LITERATURE REVIEW

Digital Learning Tools in Education

Digital learning tools encompass a wide range of technologies and platforms, including interactive software, virtual simulations, online quizzes, learning management systems (LMS), and digital textbooks. These tools are designed to enhance the educational experience by integrating technology into teaching and learning processes. The evolution of digital learning tools began with the introduction of computer-aided instruction in the late 20th century. Early tools were primarily text-based and limited in their interactive capabilities, often focusing on drills and practice exercises. However, with the rapid development of the internet and mobile technologies in the early 2000s, digital learning tools began to transform education by offering more dynamic, engaging, and personalized learning experiences (Merkle et al., 2022). Platforms such as Google Classroom, Kahoot!, and Microsoft Teams have become increasingly popular in classrooms because of their ability to facilitate real-time collaboration, feedback, and engagement (Ismail & Mohammad, 2017).

Currently, trends in digital learning focus on adaptive learning technologies, which use artificial intelligence to tailor content to the learner's pace and needs. Additionally, the COVID-19 pandemic accelerated the adoption of digital tools globally, leading to more widespread use of virtual classrooms, e-learning platforms, and hybrid learning environments (Schleicher, 2020). Today, the integration of virtual reality (VR) and augmented reality (AR) technologies is emerging as a significant trend within digital learning tools, offering immersive learning experiences in disciplines such as biology, physics, and engineering (Christopoulos et al., 2018). In summary, digital learning tools play a crucial role in helping students visualize abstract concepts, conduct experiments, and apply theoretical knowledge to practical scenarios, thereby underscoring their key value in modern education, especially within STEM fields. For international students adapting to new educational systems, these digital tools can also act as key mediators, supporting both academic integration and social connection within host institutions (Lee & Park, 2024).

STEM Education in Asia and Europe

STEM education has been identified as a key driver of economic growth and technological innovation, with countries in both Asia and Europe investing significantly in strengthening their STEM curricula. In Asia, countries such as China, Japan, and South Korea have robust STEM education systems, driven by a strong cultural emphasis on academic achievement and government policies aimed at fostering innovation. For instance, China's Ministry of Education has introduced national strategies to enhance STEM education, focusing on integrating technology and innovation into the curriculum to better prepare students for the future workforce (Ma, 2021). Japan's focus on problem-solving and interdisciplinary STEM learning has helped create a system in which students are encouraged to explore real-world problems through technology and engineering-based approaches (Takayama & Lingard, 2021).

In Europe, countries such as Germany, the United Kingdom, and Finland also emphasize the importance of STEM education, with distinct approaches that integrate hands-on learning and cross-disciplinary collaboration. Finland's education system, which is often ranked among the best globally, integrates STEM across various subjects from an early age, fostering critical thinking and problem-solving skills through inquiry-based learning (Sahlberg, 2021). Germany's dual education system combines classroom instruction with practical training in STEM fields, offering students early exposure to industry practices (Graf et al., 2014). However, notable differences exist between Asian and European STEM education systems. While Asian countries tend to focus on rote memorization and rigorous standardized testing, European systems generally promote creativity and experiential learning (Marginson et al., 2013).

Impact of Digital Learning Tools

Numerous studies have explored the effectiveness of digital learning tools in STEM education, highlighting both their benefits and challenges. Research has shown that digital tools can significantly enhance student engagement, motivation, and learning outcomes. For example, a study conducted by Anderson and Barnett (2013) revealed that students who used digital simulations in physics classes demonstrated a better understanding of complex concepts than those who received traditional instruction did. Similarly, a meta-analysis by Bernard et al. (2014) revealed that e-learning tools, such as interactive quizzes and multimedia presentations, improved students' academic performance in STEM subjects. These tools also allow for personalized learning, enabling students to progress at their own pace and receive immediate feedback, which can lead to improved knowledge retention and application (Khalil & Elkhider, 2016). Recent large-scale meta-analyses have further substantiated these findings, demonstrating that the integration of adaptive and AI-powered digital tools yields significant positive effects on STEM achievement across diverse cultural contexts (Chen & Zhang, 2024).

However, while the benefits of digital tools in education are well documented, gaps remain in the literature. Most studies focus on short-term outcomes, such as immediate improvements in test scores or engagement levels, without assessing the long-term effects on critical thinking, creativity, and problem-solving ability (Hwang et al., 2021). Additionally, research on the cultural and regional variations in digital tool effectiveness is limited. For instance, while digital tools have been widely adopted in both Asia and Europe, differences in pedagogical approaches and infrastructure may lead to varying outcomes. This study aims to address these gaps by providing a comparative analysis of the impact of digital learning tools in Asian and European STEM classrooms, offering insights into how these tools can be optimized to meet diverse educational needs (Watkins, 2012). Moreover, a growing body of research highlights the importance of understanding how international STEM students, who have unique cultural and educational backgrounds, interact with and benefit from these digital learning environments, a factor that is often overlooked in general studies (Aydin & Smith, 2023; Lee & Park, 2024).

METHOD

Research Design

This study employed a comparative research design that combined both quantitative and qualitative approaches to investigate the impact of digital learning tools on STEM education in Asian and European classrooms. The mixed-methods approach provided a comprehensive understanding of both measurable outcomes, such as student performance and engagement, and the more subjective perceptions of educators and students. The quantitative component focused on collecting and analyzing numerical data related to student performance through standardized test scores and surveys, offering a broad overview of the effectiveness of digital tools in different educational contexts. In contrast, the qualitative component included interviews and focus groups that explored the experiences, attitudes, and challenges faced by educators and students in integrating digital learning tools into STEM education (Creswell & Clark, 2017).

The combination of these methods allowed for triangulation, where the strengths of one method compensated for the limitations of the other, ensuring a more robust analysis. For example, while the quantitative data revealed trends in student performance, the qualitative data provided context and insights into the reasons behind those trends (Onwuegbuzie et al., 2011). This design was particularly suitable for cross-cultural studies, where educational practices, cultural norms, and technological infrastructure varied widely across regions. By comparing both numerical outcomes and personal experiences in Asian and European contexts, this study provides a nuanced understanding of the role that digital learning tools play in enhancing STEM education outcomes.

Data collection

Quantitative Data

The quantitative data were collected through surveys and standardized test scores from students and teachers in selected Asian and European classrooms. Surveys were designed to capture student engagement levels, the frequency of digital tool usage, and perceptions of the tools' effectiveness in STEM subjects. Similarly, teachers provided feedback on how digital tools influenced their teaching practices and student outcomes. The surveys utilized Likert-scale questions to quantify subjective responses for statistical analysis (Fowler Jr, 2013). In addition, standardized test scores for STEM subjects, both before and after the implementation of digital tools, were gathered to assess improvements in student performance. These data facilitated a direct comparison of learning outcomes between students using digital tools and those relying on traditional learning methods.

Qualitative Data

For qualitative data, interviews and focus groups were conducted with educators, students, and administrators. The interviews with teachers and administrators focused on the challenges and benefits of integrating digital tools into STEM education, whereas focus groups with students explored the engagement, motivation, and perceived impact of digital tools on their learning (Merriam & Tisdell, 2015). Participants were asked open-ended questions, allowing for in-depth discussions about their personal experiences with digital learning technologies. The qualitative data provided rich insights into the social and cultural factors that influence the effectiveness of digital learning tools across different regions. All the interviews and focus groups were recorded, transcribed, and analyzed using thematic analysis to identify recurring patterns and themes.

Sampling

Purposive sampling was used to select schools and participants from both Asian (China, Japan, and India) and European (Germany, Finland, and the United

Kingdom) regions. Schools were chosen on the basis of their integration of digital learning tools in STEM subjects, ensuring that the study focused on institutions with relevant experience. The criteria for participant selection included educators with at least three years of experience in teaching STEM subjects using digital tools and students who had been exposed to these tools for at least one academic year. Administrators involved in decision-making processes regarding digital tool adoption were also included. A total of 10 schools were selected from each region on the basis of their active integration of digital learning tools in STEM education and their representation of diverse educational contexts, including urban and rural settings and public and private institutions. This number was chosen to ensure a manageable yet diverse sample size, allowing for detailed qualitative and quantitative analysis while maintaining the feasibility of data collection across the two regions (Patton, 2014).

The sample size comprised approximately 1800 students (900 from each region) and 100 teachers and administrators (50 from each region). This sample size was sufficient to allow meaningful statistical analysis while providing a comprehensive qualitative exploration of diverse perspectives. Demographically, participants were chosen to represent a range of socioeconomic backgrounds, ensuring that the findings were not biased by factors such as access to technology or disparities in school funding.

Data Analysis

The quantitative data were analyzed using statistical methods to compare the impact of digital learning tools on student performance and engagement across the two regions. Descriptive statistics, including means and standard deviations, were used to summarize the survey responses, whereas inferential statistics, such as t tests and ANOVA, were employed using IBM SPSS Statistics to assess whether significant differences existed in performance and engagement between students who used digital tools and those who did not (Field, 2024). These analyses aimed to determine the extent to which digital learning tools contributed to higher student achievement in STEM subjects and how this varied across different educational contexts.

Thematic analysis was conducted using NVivo. This involved coding the data, organizing it into themes, and interpreting those themes within the context of the research questions (Braun & Clarke, 2006). Key themes included the perceived benefits and challenges of digital tool integration, regional differences in educational practices, and the role of cultural and infrastructural factors in shaping digital learning experiences. The qualitative findings were then cross-referenced with the quantitative results, enabling a comprehensive interpretation of how digital learning tools affected STEM education outcomes. This dual approach ensured that the study captured both measurable impacts and contextual factors, offering a holistic understanding of digital tool integration in STEM education.

RESULTS

Comparative Performance Metrics in STEM Subjects

In the pretest results by subject, Asian students achieved a relatively high score of 76.11 in Physics; their Chemistry and Mathematics scores were quite close at 74.91 and 74.89, respectively, while their Biology score stood at 75.35, indicating moderate performance. European students had a slightly higher pretest score (75.30) in chemistry, with comparable scores in physics (74.79) and mathematics (74.80), while their biology score was marginally lower (74.97). Overall, no significant differences were observed in pretest performance between the two regions (Figure 1).

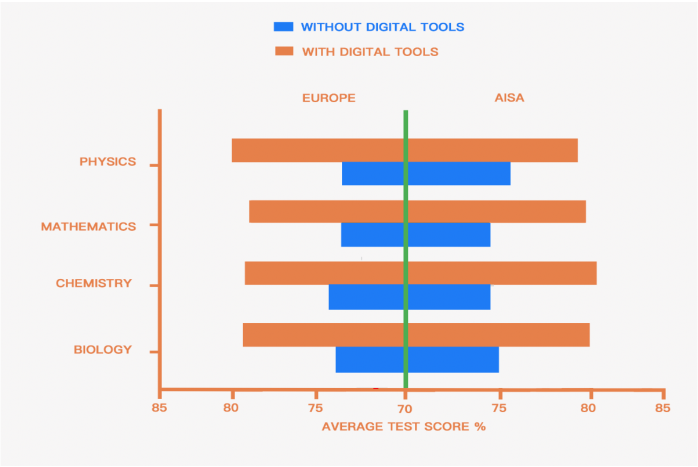

Figure 1. Comparative Performance Metrics in STEM Subjects across Regions

Note. Pretest and posttest scores are displayed for each STEM subject. Asian students (n = 900) and European students (n = 900). The figure demonstrates improvements after digital tool implementation across both regions.

In terms of the posttest results by subject, Asian students showed overall improvement across all the subjects, with relatively balanced performance. Their Chemistry score was the highest at 80.97, followed closely by Mathematics (80.49) and Biology (80.69), whereas Physics achieved a slightly lower score of 79.95, although the gaps remained minimal. European students also demonstrated an upward trend in performance, but their score distribution varied more: Physics was relatively higher at 79.80, Mathematics ranked the lowest at 78.99, and Chemistry (79.22) and Biology (79.33) fell within the middle range. Overall, Asian students' average posttest scores were slightly higher than those of their European counterparts.

In terms of pretest to posttest score improvements, Asian students demonstrated more pronounced and balanced progress across all the subjects: Chemistry scores increased by 6.06 points, Biology by 5.34 points, Mathematics by 5.60 points, and Physics by 3.84 points. European students also showed improvements, but with greater variability across subjects: Chemistry increased by 3.92 points, Biology by 4.36 points, Mathematics by 4.19 points, and Physics by 5.01 points.

In summary, after the adoption of digital tools, both Asian and European students achieved progress across the four subjects. Asian students exhibited more balanced overall improvement, with slightly superior average scores, whereas European students saw relatively stronger gains in physics—although this may also be related to factors such as exam difficulty and cultural emphasis on testing, as Asian students often prioritize exam-oriented learning.

Engagement Scores and Test Scores by Region

Table 1 shows that classroom engagement increased from an average of 2.96 to 3.82 in Asia, reflecting a 29.05% improvement rate. In Europe, engagement rose from 3.01 to 3.80, with a slightly lower growth rate of 26.25%. The marginally greater improvement in Asia might be attributed to the novelty and interactive appeal of digital tools within its educational context, as well as stronger systemic mechanisms for enhancing participation.

Table 1: Descriptive Statistics Summary of Engagement Scores and Test Performance in STEM Classrooms across Asia and Europe

Region	Aspect	Metric	Without Digital Tools	With Digital Tools	Improvement (%)
Asia	Engagement Scores	Mean	2.96	3.82	29.05
	Test Scores	Mean (STEM Average)	75.31%	80.52%	5.21
Europe	Engagement Scores	Mean	3.01	3.80	26.25
	Test Scores	Mean (STEM Average)	74.97%	79.34%	4.37

Note. Engagement scores were measured on a 5-point Likert scale.

Similarly, STEM performance improved in both regions after digital tools were adopted, underscoring their effectiveness in advancing learning outcomes.

The average STEM scores of Asian students increased from 75.31% to 80.52% (5.21% improvement), whereas those of European students rose from 74.97% to 79.34% (4.37% improvement). Greater progress in Asia could stem from students' familiarity with digital learning resources and the region's education system being more adept at leveraging such tools for academic gains.

Overall, while digital tools positively impact both regions, Asia's higher improvement rates in terms of engagement and academic performance suggest that educational culture, teaching methodology, and systemic adaptability influence the effectiveness of digital integration. This highlights the importance of contextual factors in maximizing the benefits of educational technologies.

Pre- and Postintervention Engagement Scores and Test Scores

Table 2 shows that the analysis of classroom engagement in Asia revealed 899 degrees of freedom, a mean difference of 0.86, a t-statistic of -15.750, and a p value < 0.001, indicating an extremely significant difference in engagement levels before and after the integration of digital tools. The Cohen's d value of -0.525 reflects a moderate effect size, suggesting that digital tools substantially increased classroom participation among Asian students. For academic performance, with 899 degrees of freedom, the mean difference in scores was 5.21% (t = -15.794, p < 0.001), indicating a highly significant improvement. The Cohen's d value of -0.596 represents a medium-to-large effect size, highlighting the considerable effectiveness of digital tools in enhancing Asian students' test scores.

Table 2: Inferential Statistics for Performance Metrics in STEM Classrooms

Region	Comparison	Test	Degrees of Freedom (df)	Mean Difference	Test Statistic (t)	p value	Cohen's d
Asia	Engagement Scores (Pre vs. Post)	Paired t test	df = 899	0.86	t=-15.750	< 0.001***	-0.525
	Test Scores (Pre vs. Post)	Paired t test	df = 899	5.21%	t=-15.794	< 0.001***	-0.596
Europe	Engagement Scores (Pre vs. Post)	Paired t test	df = 899	0.79	t=-14.249	< 0.001***	-0.475

	Test Scores (Pre vs. Post)	Paired t test	df = 899	4.37%	t=-13.755	< 0.001***	-0.458

Note. p values are reported as < .001; Cohen's d effect sizes are interpreted as small (0.2), medium (0.5), and large (0.8). Engagement scores were measured on a 5-point Likert scale.

In Europe, the results of the classroom engagement analysis revealed 899 degrees of freedom, a mean difference of 0.79, a t statistic of -14.249, and a p value < 0.001, confirming a statistically significant difference postintervention. The Cohen's d value of -0.475 indicates a moderate effect size, indicating a meaningful but relatively small improvement in engagement compared to that in Asia. For academic performance, with 899 degrees of freedom, the mean score difference was 4.37% (t = -13.755, p < 0.001), which is highly significant. The Cohen's d value of -0.458 falls within a moderate effect size range, suggesting that digital tools positively influenced European students' performance, although to a slightly lesser degree than in Asia did.

Collectively, the mean differences in both classroom engagement and academic performance were greater in the Asian region than in the European region, and Cohen's d values were greater. These findings underscore that the efficacy of digital tools in enhancing educational outcomes is more pronounced in Asia and is likely influenced by regional pedagogical practices, a cultural emphasis on academic achievement, or systemic adaptability to technology integration.

Comparison of Digital Tool Usage Frequencies and Regression Analysis in Classrooms

Students were categorized into groups on the basis of their weekly frequency of using digital tools: those who used these tools 1–2 times per week were classified into the low-usage group, those who used them 3–4 times per week were classified into the medium-usage group, and those who used them more than 5 times per week were classified into the high-usage group. To investigate the impact of digital tool usage frequency on students' learning outcomes, a one-way ANOVA was conducted to determine whether significant differences existed in academic performance (subject scores) and classroom engagement across the three usage frequency groups.

Table 3: ANOVA Analysis of Digital Tool Usage Frequencies among STEM Subjects across Asia and Europe

Region	Aspect	Frequency of Tool Usage	Mean Difference	Standard Error	p value
Asia	Engagement Scores	Low - medium	-0.29	0.07	< 0.001***
		Low - high	-0.29	0.07	< 0.001***
		medium - high	0.001	0.07	0.991
	Test Scores	Low - medium	-1.46	0.48	0.003**
		Low - high	-3.67	0.48	< 0.001***
		medium - high	-2.21	0.48	< 0.001***
Europe	Engagement Scores	Low - medium	-0.49	0.07	< 0.001***
		Low - high	-0.46	0.07	< 0.001***
		medium - high	0.04	0.07	0.621
	Test Scores	Low - medium	-0.87	0.48	0.071
		Low - high	-1.11	0.47	0.019*
		medium - high	-0.24	0.49	0.622

Note. The standard errors are approximate; the p values are based on post hoc comparisons (Tukey's HSD). Low usage = 1–2 times/week; medium usage = 3–4 *times*/week; high usage = more than 5 times/week.

Classroom engagement scores

The data in Table 3 indicate that there were extremely significant differences in the classroom engagement scores in Asia between the low-usage group and the medium-/high-usage group ($p < 0.001$), indicating that increasing the frequency of digital tool usage significantly enhances student engagement. However, no significant difference was observed between the medium-usage and high-usage groups ($p = 0.991$), suggesting that beyond a certain threshold, further increases in usage frequency yield diminishing returns for engagement. Similarly, in Europe, the low-usage group showed statistically significant differences compared with the medium-/high-usage groups ($p < 0.001$), reinforcing the benefits of higher usage frequency. Again, no significant difference emerged between the medium-usage and high-usage groups ($p = 0.621$), implying a plateau effect once usage reaches a moderate level.

STEM Test Performance

In Asia, significant differences in STEM test scores were found between the low-/high-usage group and the medium-/high-usage groups ($p < 0.001$), as well as between the low-usage and medium-usage groups ($p = 0.003$), demonstrating that incremental increases in digital tool usage consistently improve academic performance. In Europe, while a significant difference existed between the low-usage and high-usage groups ($p = 0.019$), the gap between the low-usage and medium-usage groups was marginally nonsignificant ($p = 0.071$), and no difference was observed between the medium-usage and high-usage groups ($p = 0.622$). This suggests that moderate increases in usage frequency positively impact scores, but additional frequency gains offer limited academic benefits.

Overall, both Asian and European regions demonstrate that appropriately increasing the frequency of digital tool usage significantly enhances classroom engagement and STEM performance. However, once usage reaches a moderate to high level, further increases fail to produce statistically significant improvements in learning outcomes. These patterns highlight the importance of strategic, context-sensitive integration of digital tools, rather than indiscriminate overuse, to maximize educational benefits.

Thematic Map of the Qualitative Findings

The thematic map (Figure 2) illustrates the major themes that emerged from the interviews and focus groups with educators and students regarding the use of digital learning tools in STEM education. The key themes include Engagement & Learning Outcomes, Teacher Challenges, and Infrastructure & Resources.

With respect to engagement and learning outcomes, subthemes such as increased motivation, improved understanding, and participation in class highlight the positive impact of digital tools on student engagement and comprehension. Students reported that interactive simulations and gamified learning environments increased their motivation to participate in class, and these tools also facilitated a better understanding of abstract STEM concepts.

On the other hand, teacher challenges were frequently mentioned, with subthemes such as teacher training, lack of support, and adapting to technology being prominent. Educators expressed concerns over insufficient training and technical support, making it difficult to adapt to new technologies. Finally, Infrastructure & Resources, with subthemes such as Unstable internet, Limited Resources, and Inequality in Access, was another critical challenge that hindered the effective implementation of digital tools, particularly in rural or underfunded schools.

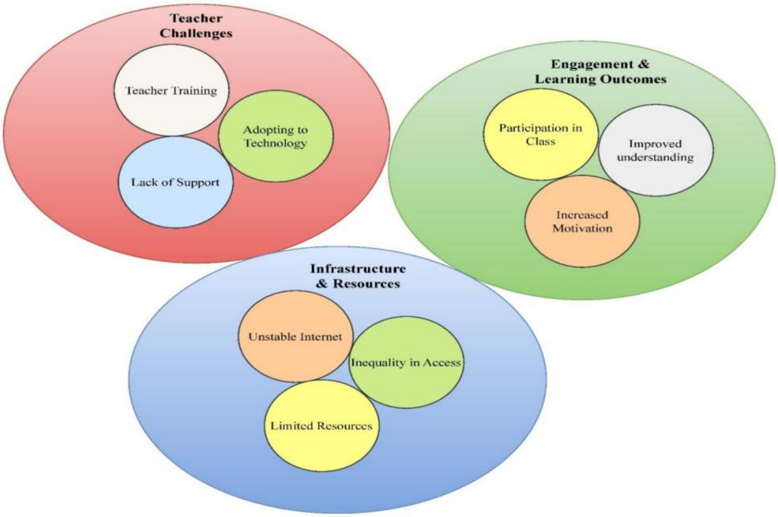

Figure 2. Thematic Map of the Qualitative Findings

Note. The thematic map illustrates the three main themes—Engagement & Learning Outcomes, Teacher Challenges, and Infrastructure & Resources—along with their associated subthemes derived from qualitative analysis.

Qualitative Themes

A detailed summary of the qualitative themes (Table 4) extracted from the interviews and focus groups. Engagement & learning outcomes was the most frequently mentioned theme, emphasizing the role of digital tools in enhancing motivation and participation in STEM classes. For instance, interactive content and simulations were cited as tools that improved student understanding, especially in subjects such as physics and chemistry.

Table 4: Summary of Qualitative Themes

Theme	Subthemes	Examples from Literature	References
	Increased Motivation	Digital learning tools, such as simulations, increased student interest in STEM subjects.	(Hrynevych et al.,2021; Yang & Baldwin, 2020)
Engagement & Learning Outcomes	Improved Understanding	Interactive content improved understanding of abstract concepts, especially in Physics and Chemistry.	(Zawacki-Richter et al., 2020; Wong et al., 2021)
	Participation in Class	Digital tools facilitated higher participation in class activities and discussions.	(Schleicher, 2020; Songer, 2013)

Theme	Subthemes	Examples from Literature	References
Teacher Challenges	Teacher Training	Teachers reported a lack of sufficient training on how to integrate digital tools effectively into the curriculum.	(Songer, 2013; Dinc, 2019)
	Lack of Support	Many teachers experienced a lack of technical and administrative support when using new digital platforms.	(Safta-Zecheria et al., 2020; Ohanu & Chukwuone, 2018)
	Adapting to Technology	Teachers faced difficulties adapting to the rapid pace of technological changes.	(Mohamed & Nadia, 2024; Sife et al., 2007)
Infrastructure & Resources	Inequality in Access	Differences in technology access between urban and rural schools hindered uniform adoption of digital tools.	(Zawacki-Richter et al., 2020; Li, 2024)
	Unstable internet	Poor internet connectivity was cited as a major challenge in many Asian classrooms.	(Akmad & Abatayo, 2024; Akmad, 2024)
	Limited Resources	Schools often lacked the funding for advanced digital learning resources like virtual labs.	(Haleem et al., 2022; Fang et al., 2019)

Note. The examples from the literature are representative statements derived from the cited sources.

The interviews revealed teacher challenges, such as the lack of adequate training on how to integrate digital tools effectively into the curriculum. Many teachers expressed a need for professional development programs that provide ongoing support. This was echoed by findings from McLoughlin (2013), who noted that insufficient training and support systems were significant barriers to the successful implementation of digital learning tools.

In Asia and Europe, the disparity between urban and rural schools in terms of technology access hampers the effective synchronized use of digital tools. Especially in Asia, poor internet connectivity is regarded as the main challenge faced by many classrooms. Schools lack basic digital tools such as virtual laboratories and effective financial support in this regard.

Student Feedback on Digital Tools

Table 5 summarizes student feedback on the use of digital tools in STEM education, which can be divided into positive and negative categories. Positive feedback included the observation that digital simulations and virtual labs helped 55% of the students better understand complex topics, particularly in subjects such as mathematics and chemistry. Additionally, 50% of the students reported that gamified tools, such as quizzes, made learning more interactive and enjoyable. Furthermore, 60% of the students appreciated the flexibility and convenience of being able to access learning materials online at any time, which helped them study at their own pace.

On the other hand, negative feedback focused on technical issues, with 40% of the students reporting that connectivity problems and platform errors disrupted their learning experiences. Distraction was another concern, with 35% of the students indicating that the ease of access to other online content during lessons caused distractions. Finally, digital fatigue was mentioned by 30% of the students, who reported feeling overwhelmed and burned out after spending long hours on digital platforms.

Table 5: Student Feedback on Digital Tools

Feedback Category	Specific Feedback	Frequency (%)
Positive Feedback	Digital simulations and virtual labs helped students understand complex topics.	55%
	Gamified tools (e.g., quizzes) made learning more interactive and enjoyable.	50%
	Students appreciated being able to access learning materials online anytime.	60%
	Digital tools enhanced collaborative projects through shared platforms.	45%
Negative Feedback	Connectivity problems and platform errors disrupted learning experiences.	40%
	Easy access to other online content caused distractions during learning.	35%
	Long hours spent on digital platforms led to burnout and reduced focus.	30%
	Some students missed the direct interaction and feedback from teachers in the classroom.	45%

Note. Frequencies represent the percentage of students (out of 900 in each region) who mentioned the specific feedback during focus groups.

Teacher Perceptions of Digital Learning Tools in STEM Education

Table 6 provides a detailed breakdown of teachers' perceptions of digital learning tools in STEM education across Asia and Europe. In Asia, 85% of teachers reported that digital tools improved student engagement, and they cited increased participation and motivation as key benefits. However, 15% of the teachers expressed concerns about the lack of infrastructure and reliable internet access, which they viewed as significant challenges to effective digital tool implementation.

Furthermore, 80% of the teachers in Asia reported that digital tools enhanced students' understanding of complex STEM concepts, particularly through the use of simulations and visual aids. However, 20% of the teachers indicated that limited training and technical support were ongoing challenges. With respect to classroom management, 75% of the teachers reported that digital tools streamlined lesson delivery and assessments, whereas 25% expressed concerns about the high costs associated with implementing advanced digital tools.

In Europe, teacher perceptions were similarly positive, with 90% of teachers reporting improved student engagement due to the use of interactive activities. However, 10% of the teachers raised concerns about overreliance on digital tools and the reduction in interaction in the classroom. Additionally, 88% of teachers in Europe reported that digital tools improved students' comprehension of abstract STEM concepts, particularly through virtual labs and multimedia. However, 12% noted that teacher burnout due to constant adaptation to new technology was a growing concern.

Table 6: Teacher Perceptions of Digital Learning Tools in STEM Education

Region	Perception Category	Teachers Reporting Positive Impact (%)	Teachers Reporting Challenges (%)	Benefits	Challenges
Asia	Improved Student Engagement	85%	15%	Increased student participation and motivation	Lack of infrastructure and reliable internet access
	Enhanced Understanding of STEM Concepts	80%	20%	Helps students grasp complex concepts with simulations and visual tools	Limited training and technical support
	Effective Classroom Management	75%	25%	Digital tools streamline lesson delivery and assessments	High costs of implementing advanced digital tools
Europe	Improved Student Engagement	90%	10%	Increased engagement through interactive activities	Overreliance on digital tools and reduced face-to-face interaction
	Enhanced Understanding	88%	12%	Improves comprehension of abstract	Teacher burnout due to constant

Region	Perception Category	Teachers Reporting Positive Impact (%)	Teachers Reporting Challenges (%)	Benefits	Challenges
	of STEM Concepts			STEM subjects through virtual labs and multimedia	adaptation to new technology
	Effective Classroom Management	80%	20%	Facilitates lesson planning and resource sharing	Issues with maintaining student focus in hybrid learning models

Note. Data were derived from surveys of 50 teachers per region.

Finally, 80% of the European teachers reported that digital tools facilitated lesson planning and resource sharing, whereas 20% mentioned that maintaining student focus in hybrid learning models was challenging. These perceptions highlight the complex nature of digital tool implementation in STEM education, with both significant benefits and challenges being reported by teachers across regions.

Keywords from Educators

Table 7 provides key quotes from educators, summarizing their experiences and perceptions of digital learning tools in STEM education. One educator remarked, *"Using digital simulations truly helps students visualize complex concepts they otherwise struggle with,"* reflecting the positive impact of digital tools on student comprehension in subjects such as physics and chemistry. Many educators echoed this sentiment, noting that simulations and other interactive content helped students grasp abstract concepts more effectively. However, educators also expressed frustration with the lack of training. As one teacher stated, *"The biggest issue for me has been the lack of training. I'm expected to use these tools, but I don't know how."* This quote illustrates the widespread need for professional development programs that focus on integrating digital tools into the curriculum effectively. Additionally, issues related to infrastructure were also common. For instance, one educator mentioned, *"It's hard to rely on digital tools when our internet connection keeps dropping during lessons,"* highlighting the technical difficulties that many schools face, particularly in underfunded areas.

Table 7: Key Quotes from Educators

Theme	Key Quote	Additional Insights/Observations
Engagement & Learning Outcomes	*"Using digital simulations truly helps students visualize complex concepts they otherwise struggle with."*	Educators observed that visual tools in Physics and Chemistry increased comprehension.
Motivation & Participation	*"Students are much more motivated when they can interact with the material, especially through gamified quizzes."*	Gamified tools (e.g., Kahoot!) were cited as a major factor in boosting classroom engagement.
Teacher Challenges	*"The biggest issue for me has been the lack of training. I'm expected to use these tools, but I don't know how."*	Many educators indicated a need for better professional development to effectively use digital tools.
Infrastructure & Resources	*"It's hard to rely on digital tools when our internet connection keeps dropping during lessons."*	Unstable internet access was commonly reported in rural and underfunded schools, limiting effectiveness.
Adapting to Technology	*"I find it overwhelming to keep up with the constant updates in educational technology."*	Teachers expressed frustration with the pace of technological advancement, creating stress and burnout.
Student-Teacher Interaction	*"Although digital tools are useful, I miss the face-to-face interaction with students during discussions."*	Some educators felt that digital tools reduced personal interaction, affecting relationship building.
Access & Equity	*"Not all of my students have access to the devices they need for digital learning at home."*	Digital inequality was a major concern, with disparities in access to technology for at-home learning.
Professional Development	*"We need ongoing support, not just a one-time training session, to truly integrate these tools into our teaching."*	Educators highlighted the importance of continued professional development in adapting to new technologies.

Note. Quotes are verbatim from interviews and focus groups; additional insights are synthesized from researcher observations.

DISCUSSION

The results of this study indicate that digital learning tools significantly enhance student outcomes in STEM education, as reflected in both quantitative and qualitative data. Across all the subjects—mathematics, physics, chemistry, and biology—students demonstrated improved test scores and higher engagement levels when digital tools were integrated into their learning. For instance, the comparative performance metrics reveal an average test score improvement of more than 4% in both Asian and European classrooms after the introduction of digital tools. This suggests that technology has a substantial positive impact on comprehension and academic performance, particularly in subjects requiring complex problem-solving, such as physics and chemistry.

One of the most prominent themes in the findings was the role of digital tools in fostering student engagement and motivation. The increased use of interactive simulations, digital quizzes, and virtual labs allowed students to engage with the material more actively, making learning more enjoyable and meaningful. Engagement scores increased by more than 26% in both regions, highlighting the ability of the tools to enhance classroom dynamics and promote active learning. These findings align with the literature, where studies such as Bond and Bedenlier (2019) and Bond et al. (2020) have consistently emphasized that digital tools can make abstract STEM concepts more accessible by allowing students to visualize and manipulate content interactively.

However, the effectiveness of digital tools is not uniform across all educational contexts. The qualitative findings suggest that the integration of technology varies across regions, primarily because of differences in infrastructure, access to technology, and teacher training. Particularly in Asia, inequality in access to digital tools and unreliable internet connectivity were major barriers. Students in these areas struggled to fully engage with digital learning because of limited resources, which hindered the consistent use of digital platforms. In contrast, schools with better infrastructure and more frequent use of digital tools reported greater improvements in student performance, as evidenced by the higher test scores and engagement rates in European classrooms.

Teacher perceptions also played a crucial role in the effectiveness of technology integration. This study revealed that teachers who received sufficient training and technical support were better equipped to integrate digital tools into their classrooms, leading to more effective use of these resources. However, teachers who lacked adequate training expressed difficulties adapting to new technologies, which often resulted in lower levels of engagement and performance in their classrooms. These findings underscore the need for ongoing professional development and support systems for educators to ensure the successful implementation of digital learning tools. This aligns closely with the conclusions of Williams and Lee (2025), who reported in their comparative study that teacher digital competence acts as a critical mediator, explaining much of the variance in student outcomes across different education systems.

The findings from this study align closely with those of previous research while offering new insights into the use of digital learning tools in STEM education. Prior studies, such as those by Gray and DiLoreto (2016) and Means et al. (2016), have demonstrated that digital learning tools contribute positively to student engagement and performance, particularly in subjects such as mathematics and science. This study's findings, which show significant improvements in test scores and engagement levels, reinforce these earlier conclusions. The use of interactive tools such as simulations and quizzes was especially effective in driving these outcomes, as seen in both Christensen et al. (2014) and Voogt et al. (2013), who also noted the importance of interactivity in promoting deep learning.

In terms of regional differences, this study contributes to the ongoing discussion regarding the digital divide, which has been extensively studied in works such as Sun and Metros (2011) and Van Dijk (2020). Tiene (2002) highlighted the disparities in digital access across different socioeconomic regions; the current study provides concrete data on how this divide manifests in the educational outcomes of students in Asia and Europe. For example, students in rural areas of Asia reported significant challenges with access to digital resources, similar to the findings of Van Deursen and Van Dijk (2019), who emphasized the need for infrastructural improvements in these areas to bridge this gap.

Another important contribution of this study is its focus on teacher preparedness and the need for continuous professional development, an issue highlighted by Canals and Al-Rawashdeh (2019) and Mouza (2019). Many teachers in this study expressed concerns about the lack of ongoing support and training, which hindered their ability to fully integrate digital tools into their teaching practices. This finding is consistent with that of Canals and Al-Rawashdeh (2019), who reported that insufficient training was among the primary barriers to the successful implementation of technology in classrooms. The results of the current study reinforce these findings, indicating that teachers in both regions—Asia and Europe—felt ill prepared to address the rapidly evolving technological landscape in education.

Overall, this study contributes to the body of knowledge by reinforcing the effectiveness of digital learning tools in enhancing STEM educational outcomes while drawing attention to critical barriers such as infrastructure and teacher support. Moreover, providing a comparative analysis between Asian and European classrooms highlights the need for region-specific interventions to address the digital divide, echoing recommendations from Czerniewicz et al. (2020) and Ferri et al. (2020), who called for more equitable access to digital resources and better professional development for educators.

Implications for Educators and Policymakers

The results of this study provide several key implications for educators and policy makers aiming to improve the use of digital learning tools in STEM education. One of the primary recommendations is the need for ongoing professional development programs that equip teachers with the necessary skills to effectively integrate technology into the classroom. As shown by the significant improvements in student engagement and performance when digital tools are properly implemented, ensuring that teachers are trained to use these tools is critical. Policymakers should allocate resources for continuous teacher training, emphasizing not only the technical use of digital tools but also how to incorporate them into pedagogical strategies. For instance, Sheridan et al. (2019) highlight the importance of creating teacher education programs that focus on digital pedagogies and how to adapt teaching styles to leverage these technologies fully.

In addition, there needs to be a focus on improving infrastructure, especially in rural and underfunded schools. The disparities in access to reliable internet and technology, as identified in this study, hinder the full potential of digital learning tools. Policymakers should prioritize funding for high-speed internet access and device provision in underserved areas. Selwyn (2019) emphasizes that the digital divide is a critical barrier to equitable education and that this divide must be addressed through targeted investments in infrastructure.

For educators, the results of this study suggest that blended learning models may offer the most benefits. By combining face-to-face instruction with digital tools such as simulations, quizzes, and virtual labs, educators can create dynamic learning environments that enhance student engagement and understanding. Means et al. (2016) argue that blended learning approaches tend to yield better outcomes than fully digital or traditional models do, as they provide a balance between direct teacher interaction and digital engagement.

Policymakers should also consider standardizing the integration of digital tools across curricula. Clear guidelines for technology use in classrooms, supported by national or regional educational bodies, could ensure a more consistent and effective implementation of these tools. Initiatives such as creating learning management systems (LMSs) accessible to all schools can streamline the use of digital resources and allow for collaborative learning across different regions.

Limitations and Future Research Directions

While this study provides valuable insights, it has several limitations. One limitation is the geographical scope, as the study focused only on Asian and European classrooms. Future research could include data from other regions, such as Africa and Latin America, to provide a more comprehensive understanding of how digital tools are used globally in STEM education. Additionally, the study relied heavily on self-reported data from educators and students, which may introduce response biases, such as overreporting positive outcomes.

Another limitation is the cross-sectional nature of the study, which provides only a snapshot of the current use of digital tools. Longitudinal studies that track the impact of digital learning tools over time could provide more nuanced insights into their long-term effectiveness. Future research could also explore student-specific factors, such as learning styles and socioeconomic status, to better understand how these tools affect different types of learners.

Finally, there is a need for further exploration into teacher training programs, focusing on how different professional development models impact the integration of digital tools. Research that investigates the most effective strategies for training educators could provide valuable guidance for policymakers aiming to improve digital learning outcomes.

CONCLUSION

The results of this comparative study provide compelling evidence that the integration of digital learning tools significantly enhances STEM education outcomes in both Asian and European classrooms. Across various STEM subjects, students demonstrated marked improvements in both engagement and academic performance following the introduction of digital tools such as simulations, quizzes, and learning management systems. The findings suggest that digital tools are especially effective at fostering student motivation and active participation, which are critical for improving learning outcomes in subjects requiring complex problem-solving skills, such as physics. While the benefits of digital tools were evident, the study highlights important challenges that must be addressed for their effective implementation. The regional disparities in access to digital infrastructure, particularly in rural or underfunded schools, underscore the need for policy interventions aimed at ensuring equitable access to technology. Furthermore, the lack of on-going teacher training and technical support emerged as significant barriers to the successful integration of digital tools. To maximize the potential of these tools, educators require continuous professional development to adapt to evolving educational technologies. This study contributes to the growing body of knowledge on the use of digital learning tools in education by providing a nuanced understanding of their impact across different regions. It offers practical recommendations for educators and policymakers, emphasizing the need for equitable access to technology, continuous teacher training, and the adoption of blended learning models to enhance STEM education outcomes. Future research should focus on exploring the long-term effects of digital tools on critical thinking and problem-solving skills and examining their impact in regions beyond Asia and Europe to provide a more comprehensive global perspective.

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- √ *None*
- ▢ *Some sections, with minimal or no editing*
- ▢ *Some sections, with extensive editing*
- ▢ *Entire work, with minimal or no editing*
- ▢ *Entire work, with extensive editing*

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