

Development of Digital Technology-Based Mathematics Learning

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ABSTRACT

The development of digital technology has brought changes to the way mathematics learning is designed, implemented, and evaluated. Digital technology no longer functions merely as a medium for delivering instructional content but has evolved into a means of visualizing concepts, conducting exploration, solving problems, communicating, receiving feedback, and supporting more flexible learning. This study aims to analyze the development of digital technology-based mathematics learning, its forms of utilization, the benefits it provides, and the challenges arising from its implementation. This study employs the library research method by reviewing various scientific articles, books, research reports, and academic documents relevant to digital technology and mathematics education. The analysis was conducted through the stages of source identification, literature selection, thematic classification of information, interpretation, and synthesis of the findings. The results show that the development of technology in mathematics learning has progressed from the use of presentation media and multimedia toward interactive applications, mathematical software, online learning platforms, simulations, educational games, data-driven learning, and the utilization of artificial intelligence. Technology provides opportunities to enhance conceptual visualization, student engagement, learning flexibility, and problem-solving abilities. However, its implementation still faces challenges, including teachers' digital competence, limited infrastructure, unequal access, the quality of learning resources, and the risk of inappropriate technology use. Therefore, digital technology should be positioned as a pedagogical tool that supports the thinking process.

Keywords: Digital Technology, Digital Literacy, Educational Innovation, Learning Media, Mathematics Learning

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INTRODUCTION

The development of digital technology is one of the important changes affecting almost every aspect of life, including education. The use of technology in education has evolved from merely serving as a tool for delivering information into becoming part of a learning environment that enables students to access learning resources, interact with learning materials, conduct explorations, receive feedback, and learn more flexibly (Al Ayyubi et al., 2024). UNESCO places educational technology within a broader framework that encompasses relevance, equity, sustainability, and quality. Therefore, the use of technology in education should not be evaluated solely based on its sophistication but also on its suitability to students' needs and learning objectives. This change is particularly significant in mathematics learning. Mathematics is not only concerned with the ability to perform calculations but also involves conceptual understanding, reasoning, modeling, representation, communication, and problem solving. Many mathematical concepts are abstract in nature, which often makes it difficult for students to understand them when they are presented only through symbols, formulas, or verbal explanations. Digital technology provides opportunities to address some of these challenges through visualization, animation, simulation, dynamic graphs, object manipulation, and mathematical representations in various forms.

Along with its development, the technology used in mathematics learning has also undergone changes. In the early stages, computers and presentation media were primarily used to assist teachers in delivering instructional content. Subsequently, technology developed into mathematical software that enabled students to interact with mathematical objects. The development of the internet then made it possible for learning to take place through online platforms and learning management systems (LMS) (Adiyono et al., 2025; Andriani & Daroin, 2022). Today, these developments have expanded further with the emergence of interactive applications, simulations, educational games, data analysis, adaptive learning, and artificial intelligence. The literature indicates that research on the use of technology in mathematics education has developed extensively, although the level of technology integration in learning practices remains varied. These developments demonstrate that digital technology has the potential to transform the experience of learning mathematics. Students can learn a concept through more than one representation and directly explore mathematical relationships. For example, changes in the parameters of a function can be observed through dynamic changes in its graph. In geometry, objects can be rotated, enlarged, or manipulated, making relationships among their elements easier to observe. Such experiences can help students develop more meaningful understanding when digital activities are accompanied by questions, discussions, and reflection.

However, the use of digital technology does not automatically make mathematics learning more effective (Al Ayyubi, Rohaendi, et al., 2025). Technology may function merely as a replacement for a blackboard or textbook when it is not accompanied by changes in learning activities. Research by Bray and Tangney indicates that much of the use of technology in mathematics education research remains at the level of enhancing existing teaching practices, while truly transformative uses of technology are still relatively limited. These findings indicate that the main issue is not simply whether technology is used, but how it is used and

for what learning purposes. In addition to pedagogical considerations, the use of technology is also related to teacher readiness, infrastructure availability, student access, and the quality of learning resources. UNESCO emphasizes that the use of educational technology needs to consider appropriateness, equity, evidence of effectiveness, and sustainability. Technology should also support human interaction in education rather than replace it. In the context of mathematics learning, these issues become increasingly important because technology can provide both benefits and risks. On the one hand, technology can help students understand concepts, conduct explorations, and increase engagement (Alam et al., 2026; M. Tang et al., 2021). On the other hand, excessive use of calculators, problem-solving applications, or artificial intelligence may cause students to obtain answers without understanding the underlying thinking processes. Therefore, technology integration needs to be designed in a way that continues to position mathematical thinking as the primary goal of learning.

Based on these conditions, a review of the development of digital technology-based mathematics learning is important. Such a review is needed not only to identify the types of technology that have been used but also to understand changes in the functions of technology, the pedagogical benefits it offers, the challenges of its implementation, and the future direction of mathematics learning. Based on the foregoing discussion, this study aims to analyze the development of digital technology-based mathematics learning based on a literature review, identify the forms of technology utilization in mathematics learning, analyze the benefits and challenges of its implementation, and formulate directions for digital technology implementation that can support meaningful mathematics learning.

METHOD

This study employed the *library research* method. This method was selected because the study did not collect data directly through observations, interviews, or experiments, but instead utilized various scientific sources as a basis for obtaining, comparing, and synthesizing information regarding the development of digital technology-based mathematics learning (Rukhmana et al., 2022). The data sources consisted of literature relevant to the topic of digital technology in mathematics learning. The literature included scientific journal articles, academic books, research findings, reports from educational institutions, and other scholarly documents that provided information on the use of technology in the mathematics learning process. The literature was prioritized based on its relevance to the research focus, source credibility, clarity of information, and contribution to understanding the development of digital technology in mathematics education. Literature that discussed technology only in general without a clear connection to mathematics learning was not used as a primary source. Data collection was conducted through several stages. The first stage involved determining keywords appropriate to the research focus, such as *digital technology in mathematics education*, *technology-enhanced mathematics learning*, *digital mathematics learning*, *mathematics education technology*, and their corresponding terms in Indonesian.

The second stage involved conducting a literature search through various academic sources. The third stage involved reviewing titles and abstracts to determine the relevance of each source to the research focus. Relevant literature was then

examined in greater depth to identify information regarding the types of technology used, purposes of use, benefits, challenges, and implementation outcomes. The data were analyzed descriptively and analytically through the processes of reduction, classification, interpretation, and synthesis. Information from various sources was organized into several main themes, namely the development of digital technology, forms of technology utilization, learning benefits, the role of teachers, the use of technology for problem solving and conceptual understanding, implementation challenges, and future directions for technological development (Sugiono, 2025). Furthermore, findings from various sources were compared to identify patterns and trends. The analysis did not merely summarize the content of each source but also examined the relationships among the findings. Through this approach, the study is expected to provide a more comprehensive overview of the role of digital technology in the development of mathematics learning.

RESULT AND DISCUSSION

RESULT

The findings indicate that digital technology in mathematics education has developed gradually. This development can be observed in the changing functions of technology, from being a tool for delivering information to becoming a learning environment that enables students to actively interact with mathematical concepts. In the early stages, technology was primarily used as a presentation medium. Teachers used computers, projectors, digital images, simple animations, and videos to help deliver instructional materials. At this stage, the learning process essentially remained similar to conventional learning, but the materials were presented through digital media (Al Ayyubi, Rahmawati, et al., 2025). The next stage was characterized by the development of interactive mathematical software and applications. Technology was no longer used merely to display instructional materials but also enabled students to manipulate objects, change parameters, observe graphs, and explore mathematical relationships. This shift provided students with opportunities to learn through exploratory activities. The development of the internet further expanded the use of technology through online learning. Learning platforms enabled teachers to provide materials, assign tasks, conduct discussions, and administer assessments within a digital environment. This situation developed further when distance learning became an important necessity during the pandemic.

The subsequent development has led to the use of more interactive and adaptive technologies. Technology has increasingly been used to provide more personalized learning experiences, deliver immediate feedback, and offer various forms of learning activities (Zou et al., 2025). Recent studies on digital technology in mathematics education have identified the use of various tools, including learning applications and digital-based games, with potential benefits for student engagement, exploration, and problem-solving skills. The most recent development is marked by the use of artificial intelligence (AI). AI has begun to be used to generate exercises, provide explanations, assist students in understanding solution steps, and provide feedback. The presence of AI creates opportunities for more personalized learning, but at the same time raises concerns regarding the authenticity of students' work, dependence on technology, the accuracy of information, and students' ability to verify

information. The following section presents the development of digital technology in mathematics education:

Tabel 1. Development of Digital Technology in Mathematics Education

Development Stage	Type of Technology	Main Function
Early Digital Media	Computers, projectors, presentations	Delivering instructional materials
Multimedia	Videos, animations, digital images	Visualizing concepts
Interactive Technology	Mathematical applications and software	Exploring concepts
Online Learning	LMS and learning platforms	Providing access to and facilitating learning interactions
Simulations and Games	Simulations, educational games	Exploration and engagement
Adaptive Learning	Data-driven digital systems	Adapting to learning needs
Artificial Intelligence	AI and generative AI	Learning assistance and feedback

Based on the synthesis of the findings, the use of digital technology in mathematics education can be categorized into several forms. First, technology is used for concept visualization. Second, technology is used for practice and feedback. Third, technology is used for exploration and simulation. Fourth, technology is used for communication and collaboration. Fifth, technology is used for assessment and monitoring learning progress. This categorization shows that technology has a broader function than merely serving as a learning medium. Technology can serve as an environment that enables students to engage more actively in mathematical activities (Sofroniou, 2025). The categorization is presented in the following table:

Tabel 2. Forms of Digital Technology Use in Mathematics Education

Bentuk Form of Use	Example Activities	Skills Developed
Visualization	Dynamic graphs, interactive geometry	Conceptual understanding
Exploration	Changing variables and observing patterns	Reasoning
Simulation	Modeling mathematical situations	Mathematical modeling
Practice	Quizzes and interactive exercises	Concept mastery
Feedback	Automatic corrections and explanations	Reflection
Collaboration	Online discussions and group work	Communication
Assessment	Digital tests and assignments	Skills evaluation
AI	Explanatory assistance and practice	Personalized learning

One of the most prominent findings of the study is the potential of digital technology to support the understanding of mathematical concepts. Concepts that

were previously presented only through symbols can be displayed in the form of graphs, images, animations, or manipulable objects. For example, in learning about functions, students can observe the relationship between changes in variable values and the shape of a graph. In geometry, students can manipulate shapes so that relationships among angles, lengths, areas, and positions can be observed. Such experiences enable students to perceive mathematical relationships in a more dynamic way. The use of technology can also help connect multiple representations. Students can observe relationships among equations, tables, graphs, and contextual situations. This is important because mathematical understanding is demonstrated not only through the ability to use formulas but also through the ability to understand relationships among different representations. However, visualization should not be regarded as the ultimate goal. Students still need to be guided to explain the relationships they observe, formulate conjectures, test those conjectures, and draw conclusions. Thus, technology serves as a means of constructing understanding rather than merely providing an attractive visual display.

Digital technology also has the potential to support problem-solving skills. Students can use technology to create tables, construct graphs, conduct simulations, try different strategies, and check their results (Taranto et al., 2024). In this process, technology can accelerate exploration, giving students opportunities to consider more possibilities. For example, when solving problems involving patterns, students can use tables or graphs to identify trends before formulating generalizations. However, technology must be used carefully. If students simply enter a problem into an application to obtain an answer, the problem-solving process may actually be diminished. Therefore, learning should emphasize the processes of understanding the problem, designing a strategy, implementing the strategy, checking the results, and explaining the reasoning behind the solution. Digital technology can provide a more interactive learning experience. The use of videos, simulations, games, applications, and digital quizzes can encourage students to interact more actively with learning materials (Haryaningrum & Reza, 2023; Mansir, 2022). A recent systematic review of digital technology in mathematics education found that the use of digital tools has the potential to increase engagement, exploration, and problem-solving skills. However, engagement should not be measured solely by how frequently students use digital devices. Students may appear active while using technology without necessarily being cognitively engaged. Therefore, the desired form of engagement is cognitive engagement, in which students use technology to analyze, experiment, compare, explain, and draw conclusions.

Technology provides students with opportunities to access learning resources more flexibly. Learning materials can be revisited through videos, digital modules, interactive exercises, and online resources. Such flexibility can support students who need more time to understand the material. Students can also review explanations without having to wait for the teacher to explain them again in class. Nevertheless, independent learning does not mean that students learn without guidance. Students still need direction regarding credible sources, appropriate ways to use technology, and how to evaluate the information they obtain. The role of the teacher therefore shifts from merely delivering information to designing learning experiences, facilitating exploration, providing feedback, and guiding students' thinking processes. Teachers need to select technology based on learning objectives. Not all

learning materials require applications or digital devices. Technology should be used when it provides clear added value to the learning process. Teachers also need the ability to evaluate the quality of digital resources. Not all information available on the internet is accurate or appropriate for students' developmental levels. Therefore, the ability to select, modify, and integrate digital resources is an important component of teacher competence. The development of technology also influences the way assessment is conducted. Digital assessment enables teachers to provide questions, collect responses, obtain results, and provide feedback more quickly. Technology also allows for the use of more diverse forms of assessment, such as interactive questions, simulations, digital projects, and problem-solving activities (Adha & Mentari, 2022; Hakim & Yulia, 2024; Manurung et al., 2026).

However, digital assessment should not focus solely on the final answer. In mathematics, the thinking process is an important component that needs to be assessed. Therefore, assessment should provide students with opportunities to explain their strategies, provide reasoning, and demonstrate their solution processes. The findings indicate that the benefits of digital technology cannot be separated from various challenges. One of the main challenges is the digital access gap. Not all schools and students have adequate devices, internet connectivity, and digital facilities. UNESCO also identifies access to technology, teacher readiness, and governance as important conditions for the successful integration of educational technology (Izazi & Fudhla, 2022). Another challenge is teacher competence. Technical proficiency in using applications does not necessarily mean that teachers are able to use them pedagogically. Teachers need to understand when technology should be used, for what purposes, and how digital activities can promote mathematical competencies. Another challenge is the potential for distraction and dependency. Digital devices provide access to abundant information and entertainment, so their use needs to be clearly directed. In mathematics education, the risk of dependency also arises when students use applications to obtain answers without understanding the underlying process.

DISCUSSION

The findings indicate that the development of digital technology does provide numerous opportunities; however, the presence of technology does not automatically lead to the transformation of learning. Technological changes need to be accompanied by changes in instructional design (Mhlongo et al., 2023). The findings of Bray and Tangney show that many implementations of technology in mathematics education still function primarily as enhancements to existing teaching practices. In other words, technology is used to make existing activities faster or more engaging, but it does not necessarily change the way students construct mathematical knowledge. This is an important consideration because the primary goal of technology integration is not to make learning appear modern, but to improve the quality of the learning experience. Technology has pedagogical value when it is capable of providing experiences that are difficult to achieve through previous methods, such as dynamic graph exploration, simulations, object manipulation, or faster feedback. One of the major contributions of digital technology is that it provides students with opportunities to view mathematics through multiple representations. Students can connect symbols with images, graphs, tables, and real-world situations.

The use of multiple representations can help reduce difficulties in understanding abstract concepts. However, the success of technology still depends on the design of learning activities. If teachers merely display an animation without asking students to interpret what is happening, technology may not necessarily lead to deep conceptual understanding. Therefore, technology should be used in conjunction with investigative activities. Students can be asked to make predictions, manipulate objects, observe changes, identify patterns, and explain their observations. Quality mathematics education should not stop at the ability to obtain an answer. Students need to understand why a particular strategy is used and why an answer can be considered correct (Al Ayyubi & Rohmatulloh, 2023). Technology can support this process when it is used as an exploratory tool. Students can try different strategies, test conjectures, compare results, and observe the consequences of particular changes. Thus, the use of technology should be directed toward strengthening higher-order thinking skills. Findings from recent studies indicate that digital technology has the potential to support problem-solving, exploration, and student engagement.

The effectiveness of technology is determined not only by the type of device used but also by the integration of technology, content, and instructional strategies. Teachers need to consider the characteristics of mathematical content before selecting appropriate technology. For example, visualization technologies are highly suitable for topics that require dynamic representations. Simulations can be used for topics that require exploration. Digital platforms can be used for learning activities that require flexible access to materials and communication. Therefore, there is no single technology that is best suited for all mathematics topics. Technology selection should be based on instructional needs. Artificial intelligence (AI) has become an increasingly important development in education. AI has the potential to provide explanations, generate practice questions, provide feedback, and support personalized learning (K. H. D. Tang, 2024). However, AI also presents new challenges. Students may use it to obtain answers instantly without engaging in the thinking process. Therefore, the use of AI in mathematics education needs to be directed toward activities that require students to verify, compare, explain, and evaluate answers. In this context, teachers need to modify the nature of learning tasks. Tasks should not simply require final answers but should also ask students to provide reasoning, strategies, reflections, or proofs. In this way, technology can be used to strengthen the thinking process rather than replace it.

The development of digital technology must also be viewed from the perspective of equity. Schools with comprehensive facilities can use technology more extensively, whereas schools with limited resources may face difficulties in implementing digital learning. UNESCO emphasizes that educational technology should adhere to the principles of appropriateness, equity, evidence-based practice, and sustainability. This means that the use of technology needs to consider the actual conditions of students and schools rather than simply following the latest technological trends. Therefore, technology implementation does not always require expensive or complex devices. Simple technologies that are appropriate to instructional needs can provide significant benefits when they are pedagogically designed. Teachers are one of the most important factors determining the success of technology integration. Teachers need not only to know how to operate applications but also to understand how to use them to achieve learning objectives.

Teacher competency development should encompass three aspects. First, technical competence in using technology. Second, pedagogical competence in designing technology-based learning activities. Third, evaluative competence to assess whether technology genuinely provides benefits to the learning process (Oktarika et al., 2026; Rachmaningtyas et al., 2025; Widodo et al., 2026). Therefore, teacher training should not stop at introducing applications. Teachers need opportunities to design learning activities, experiment with technology, evaluate the outcomes, and make improvements. Based on the synthesis of the literature, the development of technology-based mathematics education tends to move toward learning that is more interactive, personalized, adaptive, and data-driven. Technology will increasingly be used to provide different learning experiences according to students' needs. However, this direction must continue to place educational goals at the center. UNESCO emphasizes that technology should support human interaction in education rather than replace the role of teachers. Therefore, the future of mathematics education is not learning that is entirely dependent on technology, but rather learning that is able to combine the strengths of technology with the power of pedagogical interaction between teachers and students

CONCLUSION

Based on the findings of the literature review, it can be concluded that digital technology-based mathematics education has developed quite rapidly. This development is characterized by a shift in the function of technology from a medium for delivering instructional materials to an interactive tool for visualization, exploration, problem-solving, communication, assessment, independent learning, and learning personalization through artificial intelligence. Digital technology provides several opportunities in mathematics education. The use of technology can help students understand abstract concepts through visualization and multiple representations, explore mathematical relationships, receive feedback, access learning resources flexibly, and develop problem-solving skills. Findings from various studies indicate the positive potential of digital technology for student engagement and the mathematics learning process, although its impact is not always consistent across different contexts. On the other hand, technology is not an automatic solution to all challenges in mathematics education. Its effectiveness is strongly influenced by instructional design, teacher competence, student characteristics, the type of learning content, the quality of the technology, and the learning environment.

Unequal access, limited infrastructure, teachers' digital competence, distraction, dependence on applications, and the uncontrolled use of AI are among the issues that need to be considered. Therefore, the use of digital technology in mathematics education should be oriented toward achieving alignment among technology, pedagogy, and learning objectives. Technology should be used when it can provide added value to the learning process, particularly in helping students understand concepts, engage in mathematical reasoning, solve problems, and communicate mathematical ideas. Ultimately, the development of digital technology-based mathematics education should not be directed toward replacing the role of teachers with technology, but rather toward creating learning experiences that combine teachers' expertise, students' thinking activities, and the advantages of technology. Through such an approach, digital technology can serve as a means of

supporting mathematics education that is more flexible, interactive, contextual, and meaningful.

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