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Effectiveness of Digital Technology on Enhancing Mathematics Achievement of Indonesian Secondary Schools Students': A Meta-Analysis Research from 2018-2023

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Abstract: Effectiveness of Digital Technology on Enhancing Mathematics Achievement of Indonesian Secondary Schools Students': A Meta-analysis Research from 2018-2023. Objective: This study aimed to analyze the impact of digital technology on the mathematics achievement of Indonesian secondary school students through a meta-analysis. Methods: This study used a meta-analytic research design. A comprehensive literature search was conducted through Google Scholar to find relevant studies published from 2018 to 2023. The PRISMA flow diagram documented each stage of study selection, resulting in ten studies meeting the inclusion criteria. Data analysis involved calculating effect sizes using descriptive quantitative and categorizing results into small, moderate, or significant levels to provide a comprehensive summary of digital technology's impact across various educational levels and mathematics topics. Findings: The analysis revealed that digital technology had a moderate positive effect on students' overall mathematics achievement, with an average effect size of 0.417. Digital technology was more effective for junior high students with an effect size of 0.499, compared to a lower impact for senior high students with an effect size of 0.091. Among the topics analyzed, "Set" showed the highest effect size at 0.733, while "Limit of Algebraic Functions" exhibited the lowest at 0.136. Conclusion: The meta-analysis revealed that digital technology has a moderate effect on enhancing mathematics achievement among Indonesian secondary students. Digital tools are more effective for visual and conceptual topics than for abstract concepts and benefit junior high students more than senior high students. These findings highlight the need for tailored digital strategies based on content type and student level. Further research should explore features of digital tools that maximize mathematics achievement.

Keywords: digital technology, mathematics achievement, secondary school, meta-analysis, Indonesia.

▪ INTRODUCTION

In recent decades, there has been a growing emphasis on integrating digital technology into education, especially in efforts to improve students' mathematics skills. Mathematics has garnered significant attention due to its complexity and vital role in education. Digital tools like interactive learning software, simulations, and web-based applications enhance learning and help students grasp abstract mathematical concepts (Zhu, 2023). These tools not only support understanding through visualization and adaptability but also foster greater student engagement and motivation, particularly when applied thoughtfully to match educational goals.

The effectiveness of digital technology in mathematics education is a topic of debate among scholars and educators. Several studies have been conducted to assess its impact on students' mathematics achievements, resulting in mixed findings. Research suggests that using digital technology in mathematics education can positively affect student learning, particularly at the K-12 level. For example, Bray and Tangney (2017) found that interactive learning software can enhance students' understanding of

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mathematical concepts compared to traditional teaching methods. Similarly, Vallée et al. (2020) highlighted that blended learning supports knowledge retention and independent learning, enhancing students' motivation and learning achievements in complex subjects like mathematics. Furthermore, Li and Ma (2010) supported these findings, showing that computer technology enhances mathematics learning, especially when well-integrated into the curriculum.

Research has shown that using technology in the secondary school curriculum can improve students' understanding of advanced algebra (Hegedus et al., 2015). Additionally, the concrete-representational-abstract approach, supported by technology, has been practical for students struggling to understand mathematical concepts (Bouck et al., 2018). Furthermore, mathematical analysis software has been highlighted as providing significant pedagogical opportunities to develop students' mathematical thinking (Pierce & Stacey, 2010).

Despite the positive findings, there are still challenges in integrating technology into mathematics instruction. For instance, research by Özgün-Koca, Meagher, and Edwards (2010) highlighted the importance of developing teachers' Technological Pedagogical Content Knowledge (TPACK) to ensure the effective use of technology in mathematics education. Additionally, Schenke et al. (2016) found that aligning game design features with state mathematics standards does not always reflect the intended learning outcomes, emphasizing the need for critical thinking in implementing educational technology. Furthermore, Juandi, Kusumah, and Tamur (2021) found that while digital tools such as dynamic geometry software significantly enhance students' mathematical understanding, their effectiveness depends on several contextual factors, including technological infrastructure and teacher readiness. This finding aligns with the need for strategic approaches to address disparities in digital access and to provide adequate professional development for educators to utilize technology effectively in their teaching (Juandi, 2021).

The research suggests that access to educational technology can help make mathematics education more fair, but its use is still challenging. Warschauer and Matuchniak (2010) emphasized that integrating technology into education should not just be about giving access but how well students use these tools to meet academic goals. Their research found that things like teacher support, classroom environment, and socioeconomic status significantly impact how effective digital technology is in improving education for different groups of students. They argued that fair access to technology needs to be paired with meaningful use and results, like better academic achievement and developing 21st-century skills (Warschauer & Matuchniak, 2010).

A study conducted by Wenglinsky in 1998 found that the relationship between educational technology and mathematics achievement is not straightforward and is highly dependent on the quality of implementation. The study concluded that the impact of technology on student learning is strongly influenced by how well it is integrated into the instructional process, including teacher training and alignment with educational objectives. Therefore, providing digital tools without strategic pedagogical planning may not produce positive results in mathematics achievement (Wenglinsky, 1998).

Given the varied findings from numerous studies, there is a growing need for a comprehensive meta-analysis to synthesize the available evidence on the effectiveness of digital technology in enhancing students' mathematics achievements. Research highlights the potential of digital tools to improve student outcomes, but results are often mixed, with factors such as implementation quality and instructional design playing significant roles in effectiveness (Tamim et al., 2011; Cheung & Slavin, 2013). A meta-analysis offers a systematic approach to aggregating results from diverse studies, allowing for a robust understanding of the overall impact of technology on mathematics education. Combining findings and meta-analyzes helps clarify how digital tools can consistently enhance mathematical performance across various educational settings (Borenstein et al., 2009).

Meta-analysis is a statistical method that combines the results of multiple studies to estimate the overall effect of a particular intervention, such as digital technology, in education. It involves several key steps, including defining inclusion criteria for studies, extracting data, and calculating a pooled effect size. This method allows researchers to account for variations in sample sizes and methodologies, thereby providing a more accurate and reliable summary of the existing research (Glass et al., 1981).

Meta-analysis has become an essential tool in educational research, especially for understanding the effectiveness of various teaching strategies and interventions. By systematically synthesizing data from multiple independent studies, meta-analysis strengthens the validity of research findings and helps identify trends and generalisations that may not be apparent in individual studies. This makes it invaluable for drawing comprehensive conclusions about the impact of specific educational approaches across diverse settings and populations. Given this significance, this research aims to analyze, evaluate, and investigate the effect size of digital technology on enhancing mathematics achievement of Indonesian secondary school students.

▪ METHOD

Research Design

This study employs a meta-analytic research design to systematically analyze and synthesize the effects of digital technology on the mathematics achievement of Indonesian secondary school students. Meta-analysis is a statistical technique that combines the results of individual studies to derive a more precise estimate of the overall effect, increasing the power and reliability of the findings (Glass, 1976). By aggregating effect sizes from multiple studies, the research provides a quantitative summary of the impact of technology across various educational contexts (Borenstein et al., 2009).

Search Strategy

The academic database Google Scholar was utilised to identify studies examining the impact of digital technology on mathematics achievement among Indonesian secondary school students. Google Scholar was chosen for its extensive coverage and accessibility, facilitating a comprehensive review of relevant studies. The search focused on publications from 2018 to 2023 to ensure the inclusion of recent research aligned with the study objectives. The search utilized the following keywords: (a) digital technology, (b) mathematics achievement, (c) secondary schools, and (d) Indonesia. The data screening process was managed using a PRISMA flow diagram to systematically record inclusion and exclusion stages.

Inclusion and Exclusion Criteria

To conduct a clear and focused analysis of the impact of digital technology on mathematics achievement, specific inclusion criteria were set for selecting studies. The studies chosen met the following criteria: (a) research published between 2018 and 2023; (b) focused on Indonesian secondary school students; (c) used an experimental or quasi-experimental design; (d) included both an experimental group that used digital technology and a control group with conventional methods; and (e) provided necessary statistical data for calculating effect sizes, such as mean, standard deviation, and sample size; sample size and t-value; or sample size and p-value. Ten articles met these inclusion criteria and were selected for analysis, while studies not meeting these criteria or lacking adequate statistical data were excluded.

Data Analysis

The data analysis technique employed is descriptive quantitative statistical analysis, aimed at enhancing the statistical validity of primary research by obtaining the effect size value. Effect size refers to the difference in outcomes between the control group and the experimental group. This study utilizes secondary data collected from previous research findings. The tabulation process involves three steps: (1) identifying research variables and organizing them into appropriate columns; (2) determining effect sizes by calculating the t-values for the experimental and control groups in each study; and (3) determining the effect of the digital technology based on the effect size criteria which are classified into small effects, moderate effects, and significant effects. The effect sizes are then categorized based on statistical criteria (Becker & Park, 2011), as shown in Table 1.

Table 1. Effect size criteria (Cohen, 2013)

No	Effect Size (ES)	Category
1	$0 \leq ES < 0.2$	Low
2	$0.2 \leq ES < 0.8$	Moderate
3	$0.8 \leq ES$	High

▪ RESULT AND DISSCUSSION

The selection process for research articles in this study followed the PRISMA guidelines and comprised three main stages: identification, screening, and inclusion. Records were sourced primarily from Google Scholar (n=25) in the identification stage. Before the screening began, two records were removed due to missing source information. In the screening stage, the remaining records underwent a detailed review to assess their relevance. Specific studies were excluded at this point due to requirements for more extensive screening. Relevant reports were retrieved for further assessment, though some could not be accessed. Among the accessible reports, five were excluded for not meeting the CASP (Critical Appraisal Skills Programme) Checklist criteria. Ten studies that met all inclusion criteria were selected for the meta-analysis in the final inclusion stage. This diagram illustrates the study selection flow, from initial identification to final inclusion, ensuring that only high-quality and relevant studies were incorporated into the review.

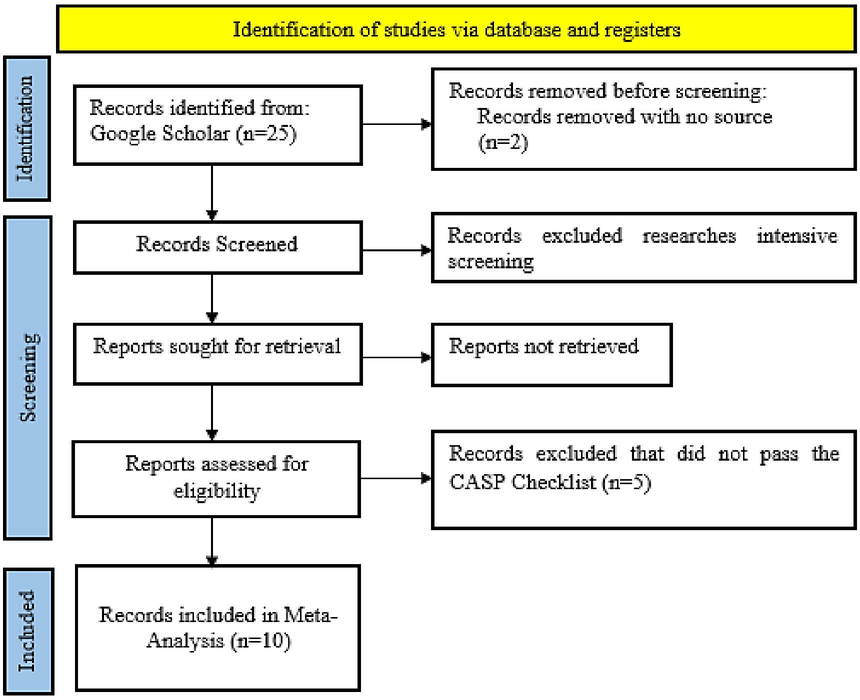

Figure 1. Search strategy using PRISMA

Table 2. Journal codes and effect size

No.	Journal Codes	Effect Size	Average Effect Size	Category
1	Journal 1	0.507	0.417	Moderate
2	Journal 2	0.733		
3	Journal 3	0.558		
4	Journal 4	0.522		
5	Journal 5	0.315		
6	Journal 6	0.697		
7	Journal 7	0.339		
8	Journal 8	0.321		
9	Journal 9	0.046		
10	Journal 10	0.136		

The effect sizes from ten studies are presented in Table 1 and analyzed through a thematic categorization approach. The results of this categorization yielded four main themes: (1) educational level differences, (2) mathematics topics, (3) the influence of digital tools, and (4) effectiveness of digital technology in mathematics achievement.

Theme 1. Educational Level Differences

The analyzed articles calculated the average effect size values based on the educational levels, including junior high school and senior high school. Out of the ten education articles reviewed, eight focused on the junior high school level, while two examined the impact of digital technology on senior high school students. The calculated average effect size and its classification for each educational level presented in Table 3.

Table 3. Effect size of digital technology in enhancing indonesian students' mathematics achievement based on educational levels

Educational Levels	Journal Codes	Effect Size	Average Effect Size	Category
Junior High School	Journal 1	0.507	0.499	Moderate
	Journal 2	0.733		
	Journal 3	0.558		
	Journal 4	0.522		
	Journal 5	0.315		
	Journal 6	0.697		
	Journal 7	0.339		
	Journal 8	0.321		
Senior High School 10	Journal 9	0.046	0.091	Low
	Journal 10	0.136		

In Table 3, the analysis of several articles shows the impact of digital technology on enhancing the mathematics achievement of Indonesian students at different school levels. The analysis covers junior high school and senior high school. At the junior high school level, eight articles indicate an average effect size of 0.499, putting it in the moderate category. This suggests that digital technology moderately enhances mathematics achievement at this level. For the senior high school level, two articles show an average effect size of 0.091, falling into the low category. This suggests that digital technology has a low impact on enhancing mathematics achievement at the senior high school level.

Senior high school students may experience reduced benefits from digital tools, as their curriculum often involves more abstract mathematical concepts that require deeper, often non-visual, cognitive processes. This aligns with research by Mandasari et al. (2024), which found that interactive tools had more pronounced effects on younger learners due to their inclination toward visual and hands-on learning. Additionally, studies by Turmuzi and Jailani (2022) indicated that junior students show higher engagement and learning retention when digital tools are employed. Therefore, these results are consistent with previous literature that supports digital technology's greater effectiveness for foundational mathematics learning among younger students.

Theme 2. Mathematics Topics

The analyzed articles also explored the impact of digital technology on students' mathematics achievement across various mathematics topics. Table 4 presents an analysis of the effect of digital technology on students' mathematics achievement based on specific mathematics topics.

Table 4. Effect size of digital technology in enhancing indonesian students' mathematics achievement based on mathematics topics

Topics	Journal Codes	Effect Size	Category
Set	Journal 2	0.733	Moderate
System of Linear Equations in Two Variables	Journal 4	0.522	Moderate
Statistics	Journal 5	0.315	Moderate

Algebra	Journal 6	0.697	Moderate
Square and Rectangle	Journal 7	0.339	Moderate
Limit of Algebraic Functions	Journal 10	0.136	Moderate

Based on Table 4, the effect of digital technology varied significantly, with the "Set" topic achieving the highest effect size (0.733), while "Limit of Algebraic Functions" had the lowest (0.136). The success in teaching "Set" concepts using digital technology can be explained by digital tools' inherently visual and interactive nature, which facilitate concept mapping and visualization crucial for understanding set theory. This finding aligns with Cirneanu and Moldoveanu (2024), who suggest that digital tools greatly enhance comprehension of visually structured topics, particularly through simulations and interactive materials.

On the other hand, the relatively low impact on "Limit of Algebraic Functions" aligns with prior studies suggesting that topics requiring abstract thinking may not benefit as extensively from digital interventions. Roop and Edoh (2018) discuss how conventional, instructor-led methods—like step-by-step explanations on a blackboard—support students' comprehension of complex mathematical ideas by providing clear, structured guidance. This comparison suggests that while digital tools excel in visually oriented topics, abstract subjects may require a blended approach, integrating traditional methods to optimize learning outcomes.

Theme 3. Influence of Digital Tools

Digital tools such as multimedia applications and visualization software have demonstrated effectiveness in enhancing student engagement and comprehension across various mathematical topics. Zahwa and Rakhmawati (2018) found that using Macromedia Flash for topics like the area and perimeter of rectangles significantly enhanced student understanding and engagement compared to traditional methods. Similarly, Awaluddin and Sitorus (2019) demonstrated that GeoGebra is effective for teaching systems of linear equations in two variables (SPLDV) at SMP Kemala Bhayangkari 1 Medan. By providing visual and interactive support, GeoGebra improves comprehension and encourages active participation in learning algebraic solutions.

Supporting these findings, research by Güven and Kosa (2008) examined the impact of Cabri 3D, a dynamic geometry software, on the spatial visualization skills of student mathematics teachers. Their study involved a pretest-posttest design, where students improved their abilities to visualize and manipulate three-dimensional objects through computer-based activities. The research found a significant increase in students' spatial skills after using Cabri 3D for 8 weeks, particularly in areas like mental rotations and spatial relations. This highlights the potential of dynamic geometry software in improving essential cognitive skills for mathematics, especially in fields requiring spatial reasoning and visualization.

While these tools are beneficial, studies recommend a balanced approach to prevent students from becoming overly reliant on technology. Excessive reliance on digital tools can limit students' ability to perform independent calculations and understand basic mathematical logic. This balanced approach allows students to enjoy the advantages of digital tools while preserving foundational competencies essential for mathematical proficiency.

Meta-Theme: Effectiveness of Digital Technology in Mathematics Achievement

The overarching analysis reveals that digital technology moderately enhances mathematics achievement, with an overall effect size of 0.417. This effect is influenced by educational level, topic, and tool type. Our findings correspond with Mandasari et al. (2024), who demonstrated that digital tools improve learning outcomes when integrated thoughtfully into curriculum design. Similarly, NCTM (2000) standards emphasize the need for technology in mathematics education to create a more interactive and inclusive learning environment. These findings align with this view, indicating that digital interventions, while beneficial, requirestrategic implementation to maximize their impact.

While consistent with prior studies, the results also suggest limitations related to digital technology, such as unequal access and infrastructure disparities, which can hinder its uniform effectiveness. This aligns with the challenges highlighted by Turmuzi and Jailani (2022), who identified barriers to digital learning in regions with limited access to technology. Therefore, this study supports previous research indicating the benefits of digital tools but stresses the importance of addressing infrastructural issues to ensure equal educational opportunities.

The results of this study suggest that digital technology can significantly improve mathematics achievement. However, its effectiveness depends on factors such as the specific type of technology used, the context in which it is implemented, and the availability of resources. Therefore, specific strategies and policies are needed to address these barriers and ensure the successful integration of technology-based learning in all educational settings in Indonesia.

▪ CONCLUSION

Based on the findings from the meta-analysis, it can be concluded that digital technology has a moderate effect on enhancing the mathematics achievement of Indonesian secondary school students. The average effect size of 0.417 suggests that digital tools can support mathematical learning, although the effectiveness varies depending on educational level and specific topic. Digital technology had a more pronounced effect on junior high school students than on senior high school students, indicating that younger learners might benefit more from digital interventions. This outcome emphasizes the importance of developing tailored digital learning strategies that consider the target student group.

Regarding mathematics topics, the highest impact was observed in the “Set” topic, indicating that digital interventions, such as interactive learning modules, are particularly effective for visual and conceptual mathematical topics. In contrast, the lowest effect size was recorded for the “Limit of Algebraic Functions” topic, suggesting that digital technology may be less suitable for abstract and complex mathematical concepts. Further research is recommended to explore the specific features of digital tools that contribute to these varied outcomes and to identify best practices for maximizing the impact of digital technology in mathematics education.

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