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Enhancing Mathematical Comprehension through Technology: A Systematic Literature Review on the Effectiveness of Mathematics Software

Dina Fakhriyana[1]*, Nelly Mukhibbatunni'mah[1], Muhammad Rifqi Asshofi[1], Tsalisa Zidna Ifthoriya[1]

[1]Mathematics Education, Universitas Islam Negeri Sunan Kudus, Kudus, Indonesia

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***Corresponding author:**
dinafakhriyana@uinsukuu.ac.id

Abstract: Mathematical comprehension is a fundamental objective of mathematics learning, yet many students experience difficulties in understanding abstract concepts and mathematical relationships. Various mathematics software applications have been utilized to support conceptual understanding through visualization, exploration, and interactive learning experiences. However, existing studies have predominantly examined individual software applications, yielding limited comparative evidence on their use across mathematical topics and instructional conditions. This study aims to identify the types of mathematical software commonly used in mathematics learning, analyze their effectiveness in improving students' mathematical comprehension, and examine the factors and instructional conditions that influence their effectiveness. A qualitative Systematic Literature Review (SLR) following the PRISMA framework was conducted using articles retrieved from Google Scholar through Publish or Perish between 2020 and 2024. Of the 747 records identified, 27 studies met the inclusion criteria and were included in the analysis. The findings revealed eight mathematics software applications: GeoGebra, Construct, Cabri 3D, Wingeom, Autograph, Maple, Geometer's Sketchpad, and SageMath. GeoGebra was the most frequently investigated software and was reported across various topics, particularly geometry, transformations, trigonometry, and introductory calculus. Visualization-based software was most commonly associated with geometry-related learning, whereas symbolic computation software was more frequently applied in calculus and algebra. Visualization, interactivity, and independent exploration emerged as the primary factors supporting mathematical comprehension. Furthermore, Problem-Based Learning and Discovery Learning were the instructional models most commonly associated with software-assisted mathematics learning. These findings provide practical guidance for educators on selecting mathematical software aligned with content and instructional objectives to enhance students' mathematical comprehension.

INTRODUCTION

Students often perceive mathematics as a difficult subject (Nurulaeni & Rahma, 2022). One reason is the lack of interaction and limited use of technology in learning, which makes students feel bored (Farah & Kusno, 2023). Furthermore, students need to have mathematical comprehension skills in the mathematics learning process. This ability includes comprehending mathematical ideas and concepts, the ability to connect one concept to another concept, creating mathematical representations, and designing appropriate and efficient problem-solving strategies in everyday life (Sengkey, Deniyanti Sampoerno, & Aziz, 2023).

Educators play a crucial role in addressing this challenge, namely by having the ability to design, implement, and manage more effective and efficient learning. One of the primary tasks of educators in educational institutions is to design effective learning media (Afifah Nabila Nasution & Yahfizham Yahfizham, 2024), including in mathematics learning. One way to encourage active student engagement is by utilizing information and communication technology-based tools, including software (Afifah Nabila Nasution & Yahfizham Yahfizham, 2024).

According to (Davis, 1999), software is a program containing a set of instructions for executing data processing and controlling hardware. Software functions as a link between the user (human) and the hardware by translating user commands into machine language that the hardware can execute. Thus, humans can develop software technology that operates various hardware components accurately, optimally, and efficiently.

Various mathematics software applications have been utilized to support mathematics learning, including GeoGebra, Maple, and other mathematics software applications. These applications provide different features, such as dynamic visualization, symbolic computation, and interactive exploration, which may facilitate students' mathematical comprehension. Previous studies have generally investigated the effectiveness of individual software applications. For example, GeoGebra has been widely examined as a tool for supporting geometry, algebra, and calculus learning (Simanjuntak, 2019), while (Kusumah & Ruswana, 2023) investigated the use of Maple to improve students' mathematical comprehension. Although these studies reported positive outcomes, the findings remain dispersed across different software platforms and learning contexts.

Although many studies have examined the use of individual software applications in mathematics learning, comparative evidence across different software, topics, and instructional conditions remains limited. This study addresses that gap by synthesizing evidence from multiple mathematics software platforms to compare their effectiveness across topics and identify the pedagogical conditions that support their use. The contribution of this review is to provide practical guidance for educators on selecting appropriate software aligned with mathematical content and instructional objectives, while also informing future research on software-based mathematics learning. Therefore, this study aims to: (1) identify the types of mathematical software commonly used in mathematics learning, (2) analyze the effectiveness of various mathematical software in supporting students' mathematical comprehension, and (3) examine the factors and instructional conditions that influence the effectiveness of mathematical software in improving mathematical comprehension.

METHOD

This study employed a Systematic Literature Review (SLR) approach, adapting the systematic procedures proposed by (Triandini et al., 2019) to identify, screen, evaluate, and synthesize studies relevant to mathematics software and mathematical comprehension. The

review process included: identifying the research topic, searching the literature, selecting relevant articles, analyzing and synthesizing the findings, and drafting the review.

Search strategy and data source. Articles were identified through a search in Google Scholar using the Publish or Perish application because Google Scholar provides broad coverage of educational publications and is widely used in mathematics education research. The search was limited to publications from 2020 to 2024 using the keywords "kemampuan pemahaman matematis" and "software," yielding 747 records.

Inclusion and exclusion criteria. Studies were included in this review if they met the following criteria: (1) published between 2020 and 2024; (2) published in peer-reviewed journals; (3) focused on the use of mathematics software in mathematics learning; (4) reported outcomes related to students' mathematical comprehension; and (5) provided accessible full-text articles.

The exclusion criteria were as follows: (1) non-journal publications such as theses, dissertations, or books; (2) inaccessible article links; (3) titles unrelated to mathematics software and mathematical comprehension; (4) discussions that did not address mathematics software or mathematical comprehension; and (5) studies that discussed software in general rather than mathematics software specifically. The articles were screened based on title, abstract, and full-text relevance according to the inclusion and exclusion criteria. After applying the inclusion and exclusion criteria, 27 studies were considered eligible for analysis and included in the final review.

Table 1. Exclusion Criterion Used in the Screening Process

Exclusion Criterion	Explanation	Example
Not a journal article	Articles in the form of theses, dissertations, or books are excluded.	(Manurung, 2010)
The article link cannot be accessed	The URL address cannot be accessed	(Widiastuti & Kurniasih, 2021)
Off-topic title	The article title does not reflect a focus on mathematical software and mathematical comprehension.	(Puspita, et al., 2022)
Off-topic discussion	The discussion does not focus on mathematical software and does not address mathematical comprehension skills.	(Cahyana, 2021)
Not discussing mathematical software	The article discusses software in general, not specifically mathematics software	(Setiyani et al., 2022)

The review included various types of educational studies, such as experimental, quasi-experimental, developmental, and educational intervention studies, provided that they reported outcomes related to students' mathematical comprehension through the use of mathematics software. Data were extracted from each study regarding the software type, mathematical topic, instructional model, supporting factors, and reported outcomes. The extracted data were subsequently organized into synthesis matrices and analyzed to identify patterns concerning software use, effectiveness, and instructional conditions associated with improvements in mathematical comprehension.

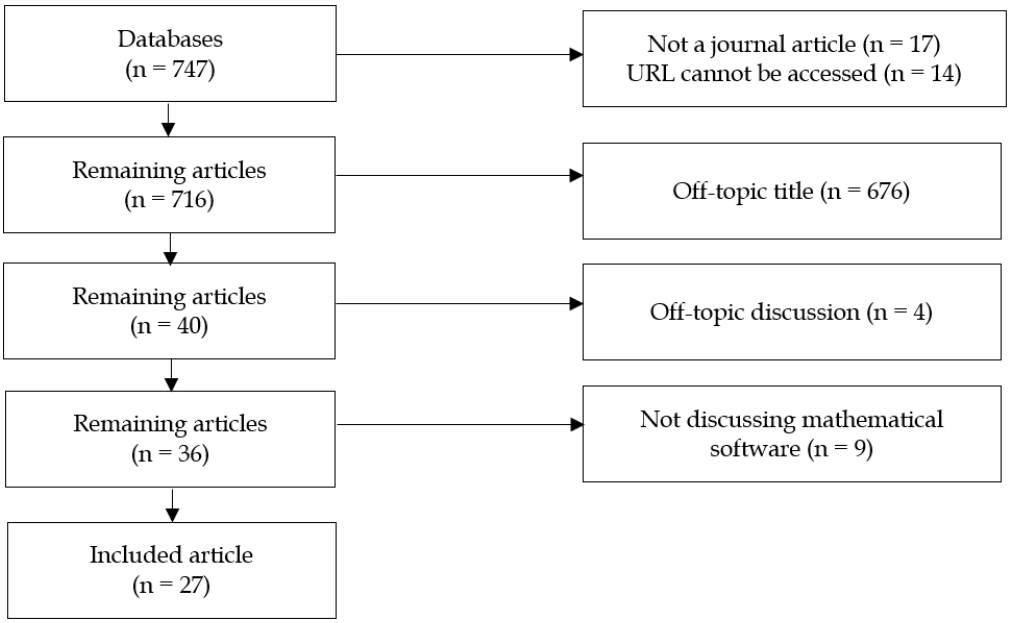

Figure 1. The PRISMA Flow Diagram in This Research

RESULT AND DISCUSSION

Result

Characteristics of Included Studies

Based on the PRISMA selection process, 27 studies published between 2020 and 2024 met the eligibility criteria and were included in this review. The studies examined eight types of mathematics software across different topics and educational levels.

Table 2. Characteristics of Included Studies

No.	Studies	Software	Mathematical Topic	Main Findings
1	(Mukarramah, Sarwo, & Suryanti, 2022)	GeoGebra	Two-Variable Linear Equation System	GeoGebra had a significant positive impact on students' conceptual comprehension and mathematical problem-solving abilities.
2	(Nulhakim et al., 2022)	GeoGebra	Solid figures/three-dimensional geometry	Students' ability to comprehend concepts related to solid figures increased through GeoGebra-assisted learning.
3	(Turmuzi, Arjudin, & Suryadi, 2021)	GeoGebra	Applied mathematics concepts	GeoGebra improved students' comprehension of mathematical concepts in the studied material.
4	(Putri et al., 2023)	GeoGebra	Geometry, Algebra, Calculus, and Statistics	Students develop their mathematical concept understanding through exploration of GeoGebra software.
5	(Koswara & Damayanti, 2022)	GeoGebra	Integral, area under the curve	GeoGebra improved students' conceptual understanding of integrals and area under the curve by enabling better visualization of function graphs and motivating students to understand integral concepts.
6	(Putri & Mukhtar, 2023)	GeoGebra	Set Concepts	Problem-Based Learning supported by GeoGebra effectively improved students' mastery of mathematical concepts.

No.	Studies	Software	Mathematical Topic	Main Findings
7	(Gunanjar & Ansari, 2023)	GeoGebra	Straight lines and angles	The implementation of GeoGebra-assisted Discovery Learning made learning active, enthusiastic, and conducive. Students demonstrated good understanding of the material on straight lines and angles. Student responses to the software were very positive.
8	(Harizahayu & Tampubolon, 2021)	GeoGebra	Mathematical logic	There was a significant linear relationship between learning success with GeoGebra and learning outcomes compared with conventional learning.
9	(Rifandi, Fatimah, & Abubakar, 2023)	GeoGebra	Two and Three Variables Linear Equation System	GeoGebra improved students' learning skills and comprehension of mathematics.
10	(Nulhakim & Susanto, 2024)	GeoGebra	Cone surface area and volume	Learning with GeoGebra improved students' understanding of spatial concepts and mathematical concepts. Hypothesis testing showed significant improvement in students' conceptual understanding of spatial figures.
11	(Sopiah et al., 2024)	GeoGebra	Geometry	GeoGebra significantly improved students' comprehension of geometric concepts.
12	(Napitupulu & Seleky, 2023)	GeoGebra	Geometric transformations	GeoGebra-supported learning improved students' comprehension of geometric transformation concepts.
13	(Hutabarat et al., 2023)	GeoGebra	Plane geometry	GeoGebra improved knowledge and skills in plane geometry.
14	(Wijayanti, Haeruman, & Hidajat, 2021)	GeoGebra	Geometric transformations	Learning transformations using GeoGebra significantly improved comprehension of concepts.
15	(Rahayu, M., et al., 2023)	GeoGebra	Trigonometric functions	GeoGebra improved students' comprehension of trigonometric function graphs.
16	(Aufa, 2024)	GeoGebra	General mathematics concepts	Problem-Based Learning (PBL) models supported by GeoGebra improved students' conceptual comprehension.
17	(AS & Maryanti, 2022)	GeoGebra	Plane figures	Guided Discovery Learning assisted by GeoGebra significantly improved comprehension of plane-figure concepts.
18	(Sucipto, 2021)	Maple	Calculus	Students' conceptual comprehension of calculus increased by 73.11 after Maple-assisted learning.
19	(Rakhmawati, 2023)	Maple	Linear systems/ elementary row operations	Maple had a positive impact and increased the effectiveness of learning elementary row operations.
20	(Listiana, Wulandari, & Wirevenska, 2020)	Autograph	Calculus	Autograph-assisted calculus materials improved students' comprehension of calculus.
21	(Z. M. Nasution, 2021)	Autograph	Cubes and Blocks	The implementation of the Numbered Head Together (NHT) model, assisted by Autograph, significantly improved students' understanding of mathematical concepts related to cubes and blocks.
22	(Akmal, 2022b)	Wingeom	Geometry	Wingeom improved comprehension of concepts compared with the control class.

No.	Studies	Software	Mathematical Topic	Main Findings
23	(Akmal, 2022a)	Wingeom	Geometry	Wingeom significantly affected students' ability to comprehend mathematical concepts.
24	(Enjelita et al., 2023)	Construct	Two-Variable Linear Equation System	The Android-based educational game developed with Construct 2 improved students' mathematical comprehension.
25	(Sinaga & Sijabat, 2023)	Cabri 3D	Cubes and blocks	Cabri 3D significantly improved students' comprehension of cube and block concepts.
26	(Riajanto, 2020)	Geometer's Sketchpad	Geometry	Geometer's Sketchpad positively affected students' attitudes and geometric comprehension.
27	(Pasaribu, Syaukani, & Ananda, 2022)	Sagemath	Integral	Students using SageMath showed better mastery of integral concepts than those who did not use it.

Table 2 presents the characteristics of the included studies, including the software used, mathematical topics, and the main findings related to mathematical comprehension. The reviewed studies included GeoGebra, Maple, Autograph, Wingeom, Construct, Cabri 3D, Geometer's Sketchpad, and SageMath. GeoGebra was the most frequently reported software, appearing in 17 of the 27 studies.

Synthesis of Mathematical Software

To provide a comprehensive overview of the reviewed literature, the identified software applications were synthesized according to their mathematical topics and reported characteristics.

Table 3. Synthesis Matrix of Mathematical Software

Software	Mathematical Topics	Reported Characteristics
GeoGebra	Plane and solid geometry, geometric transformations, trigonometric functions, integral calculus, mathematical logic, systems of linear equations	Dynamic visualization, interactive exploration, supports multiple topics, and facilitates conceptual comprehension.
Maple	Calculus, Matrix, Linear Equations	Powerful symbolic computation and procedural support
SageMath	Integral Calculus	Open-source symbolic computation and visualization
Autograph	Functions and Calculus	Graphical visualization of mathematical functions
Wingeom	Geometry	Geometry visualization and concept exploration
Cabri 3D	Solid Geometry	Strong three-dimensional visualization
Geometer's Sketchpad	Geometry	Supports dynamic geometric construction
Construct	Two-Variable Linear Equation System	Game-based mathematics learning

Factors Supporting the Effectiveness of Mathematical Software

The reviewed studies identified several factors that contributed to the effectiveness of mathematical software in improving students' mathematical comprehension.

Table 4. Synthesis Matrix of Factors Supporting Software Effectiveness

Factor	Related Software	Impact on Mathematical Comprehension
Visualization	GeoGebra, Cabri 3D, Wingeom, Geometer's Sketchpad, Autograph	Facilitates comprehension of abstract concepts through visual representation
Interactivity	GeoGebra, Cabri 3D, Geometer's Sketchpad	Supports active learning through direct manipulation
Independent Exploration	GeoGebra, SageMath	Encourages concept discovery and self-directed learning
Collaboration	GeoGebra	Promotes mathematical communication and shared problem-solving
Simulation	GeoGebra, Maple	Helps students comprehend mathematical processes dynamically
Educational Games	Construct	Increases motivation and engagement in mathematics learning
Computational Support	Maple, SageMath	Supports procedural and conceptual comprehension of complex calculations

Discussion

Comparison of Mathematical Software Across Mathematical Topics

The reviewed studies show that mathematics software is most effective when its features align with the cognitive demands of the topic being taught. GeoGebra emerged as the most versatile software because it was applied across a wide range of topics, including geometry, transformations, trigonometry, integrals, systems of linear equations, and mathematical logic. Its dynamic visualization and interactive tools help students observe relationships, manipulate objects, and represent abstract ideas more concretely. GeoGebra appeared most frequently in the reviewed studies.

By contrast, Maple and SageMath were more commonly applied in calculus and algebra-related topics. Both software applications support symbolic computation and mathematical visualization, which are useful for topics involving integrals, matrices, and algebraic operations. These characteristics support both procedural accuracy and conceptual understanding

Cabri 3D, Wingeom, and Geometer's Sketchpad were mainly used in geometry learning. These tools support spatial visualization and geometric construction, making them suitable for topics that require students to observe shapes, structures, and relationships in two or three dimensions. Autograph was mostly used for functions and calculus because it supports graphical representation and helps students connect symbolic expressions with visual forms. Construct, on the other hand, was used through a game-based approach that supported motivation and engagement rather than symbolic computation.

Overall, the findings indicate that software selection should be based on the nature of the mathematical topic and the intended learning goal. Visualization-oriented software is more appropriate for geometry and transformation topics, whereas computation-oriented software is better suited to calculus and algebra. This pattern shows that the educational value of software depends not only on the technology itself, but also on how well it matches the conceptual requirements of the lesson.

Factors Influencing the Effectiveness of Mathematical Software

Visualization was the most frequently reported factor supporting mathematical comprehension. This is important because many mathematical ideas are abstract and difficult to understand through verbal explanation alone. Dynamic visual representations help students see relationships more clearly and support the development of deeper conceptual understanding.

Interactivity was another important factor. When students can manipulate mathematical objects directly, they become more active in the learning process and can test ideas independently. This kind of interaction encourages knowledge construction rather than passive reception of information.

Independent exploration and collaboration also appeared consistently across the reviewed studies. Independent exploration allows students to investigate concepts at their own pace, while collaboration supports communication, comparison of strategies, and shared problem-solving. In addition, simulation, educational games, and computational support contributed to learning by making mathematical processes more concrete, engaging, and manageable.

Taken together, these factors suggest that mathematics software is most effective when it promotes active engagement with mathematical ideas. The strongest gains appear when software is used to reduce abstraction, support exploration, and give students opportunities to build understanding through direct experience.

Learning Models that Best Complement Mathematical Software

The review also shows that software effectiveness depends on the instructional model used during implementation. Among the reviewed studies, Problem-Based Learning and Discovery Learning were the most frequently reported instructional models associated with GeoGebra-based learning. These models are well-suited to software-based learning because they require students to explore, investigate, and construct solutions actively.

In Problem-Based Learning, students use software to analyze contextual problems and test possible solutions. In Discovery Learning, students manipulate objects, identify patterns, and formulate mathematical ideas through guided exploration. Both approaches support learner-centered instruction and make it easier for students to connect visual representation with conceptual reasoning. Collaborative learning approaches also complemented software use because they encouraged discussion, idea sharing, and joint problem solving.

However, the evidence for specific learning models paired with Maple, SageMath, Autograph, Wingeom, Cabri 3D, and Construct was limited. Therefore, conclusions about software–instructional model compatibility are strongest for GeoGebra-based studies. Future research should directly compare learning models across different software platforms to determine which combinations are most effective for specific mathematical topics.

Conceptual Implications

The overall pattern across the reviewed studies suggests that mathematics software is most beneficial when its affordances match the cognitive demands of the topic being taught. Visualization-oriented software supports spatial and geometric reasoning, whereas symbolic computation software supports procedural and algebraic work. This indicates that software should be selected not simply because it is available, but because it fits the learning objective, the topic structure, and the type of understanding expected from students.

These findings also imply that effective software use is closely tied to active knowledge construction. When software is embedded in student-centered learning environments, it can help reduce abstraction, strengthen conceptual understanding, and improve engagement. In this sense, the educational value of mathematics software lies not only in its technical features, but also in how educators design learning activities around it.

Limitations of the Review

This review has several limitations. First, the literature search was limited to Google Scholar through Publish or Perish, which may have excluded relevant studies indexed in other databases such as Scopus, ERIC, or Web of Science. Second, the included studies employed various research designs and educational contexts, which may affect the comparability of findings. Therefore, the conclusions should be interpreted as general patterns rather than definitive evidence of causal effectiveness.

CONCLUSION AND SUGGESTIONS

Based on the review of 27 relevant studies, mathematics software generally supports the improvement of students' mathematical comprehension, although its effectiveness varies depending on the mathematical topic and instructional design. GeoGebra emerged as the most versatile software because of its strong support for dynamic visualization and conceptual exploration across topics such as geometry, transformations, trigonometry, and calculus. In contrast, Maple and SageMath appeared particularly suitable for topics requiring symbolic computation, while Cabri 3D showed strong potential for spatial geometry learning. The synthesis also indicates that Problem-Based Learning and Discovery Learning were the instructional models most consistently associated with successful implementation, particularly in GeoGebra-based studies.

Practically, educators may prioritize GeoGebra for topics that require dynamic visual representation, whereas Maple or SageMath are more suitable for topics involving intensive symbolic computation, such as integral calculus and systems of linear equations. Cabri 3D is especially appropriate for spatial geometry learning. These findings can help educators select software more strategically according to learning objectives and mathematical content. For future research, further studies should examine contextual factors such as infrastructure, educators' competence, and student readiness, as well as non-cognitive outcomes including motivation, attitudes, and critical thinking. In addition, the development of valid and reliable instruments is needed to measure improvements in mathematical comprehension more accurately.

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