

Enhancing Trigonometry Learning Through Manipulative Tools: A Systematic Literature Review

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ABSTRACT

Trigonometry remains one of the most challenging topics in mathematics education due to its abstract concepts and multiple representations. Manipulative tools have been increasingly used to support students' conceptual understanding by providing concrete and interactive learning experiences. However, evidence regarding their effectiveness in trigonometry learning remains fragmented across different educational contexts and instructional approaches. This study conducted a Systematic Literature Review (SLR) to synthesize empirical evidence on the use of manipulative tools in trigonometry education. Following the PRISMA 2020 guidelines, studies published between 2020 and 2025 were identified, screened, and evaluated using predefined inclusion criteria and quality appraisal procedures. A total of 10 studies were included in the final review. The findings revealed two major categories of manipulative tools: physical manipulatives and virtual manipulatives. Both categories were associated with improvements in students' conceptual understanding, engagement, mathematical reasoning, and problem-solving performance. The effectiveness of manipulative-based interventions was influenced by factors such as instructional design, teacher facilitation, intervention duration, and

tool characteristics. The review highlights the potential of manipulative tools to enhance trigonometry learning and provides implications for classroom practice and future research on mathematics education.

INTRODUCTION

Trigonometry is a fundamental topic in mathematics education that supports learning in geometry, calculus, physics, engineering, and other STEM-related disciplines. Despite its importance, many students perceive trigonometry as difficult because it requires understanding relationships among angles, ratios, functions, graphs, and multiple mathematical representations (Ismayanti & Jatisunda., 2025). Previous studies have shown that students often develop procedural proficiency in applying trigonometric formulas but experience difficulties in constructing meaningful conceptual understanding (Cetin, 2015; Lerman, 2020). Consequently, students frequently struggle to connect symbolic representations with geometric interpretations and encounter challenges when solving unfamiliar problems or real-world situations involving trigonometric concepts (Namli, 2024). These findings suggest that effective trigonometry instruction should emphasize conceptual understanding rather than rote memorization of procedures (Tebabal & Kahssay, 2011).

One instructional approach that has received increasing attention is the use of manipulative tools. Traditional teaching methods that rely heavily on lectures and repetitive exercises often focus on procedural fluency while providing limited opportunities for students to actively construct mathematical meaning (Ferguson, 2010). In contrast, manipulative tools enable learners to explore mathematical

relationships through direct interaction, visualization, and hands-on activities (Moyer, 2001; Sowell, 1989). Such experiences facilitate inquiry-based learning and help students connect abstract mathematical ideas with concrete representations, consistent with Bruner's theory of representation (Bruner, 1966; Piaget, 1972; Larbi & Mavis, 2016). Empirical evidence suggests that manipulative-based instruction can enhance students' conceptual understanding, spatial reasoning, engagement, and overall mathematics achievement compared with conventional approaches (Carbonneau et al., 2013; Kablan, 2016).

Recent studies have explored a variety of manipulative tools in trigonometry education, including physical models, geometric constructions, interactive teaching aids, and technology-supported learning environments. These studies generally report positive effects on students' learning outcomes; however, the findings remain fragmented and methodologically diverse (Larbi & Mavis, 2016; Pozdniakov & Freiman, 2021). Variations in educational level, intervention duration, instructional design, assessment methods, and types of manipulatives make it difficult to establish clear conclusions regarding their effectiveness. Furthermore, many studies have been conducted within specific educational contexts or with relatively small samples, limiting the generalizability of their findings (Juandi et al., 2025; Ahmad & Siller, 2024).

Although numerous empirical studies have examined manipulative-based learning in mathematics education, there remains limited synthesis focusing specifically on the role of manipulative tools in trigonometry learning. Existing studies are scattered across different educational settings and employ diverse methodological approaches, making it difficult for educators and researchers to identify overall trends, effective practices, and remaining research gaps. Consequently, a comprehensive review is needed to consolidate existing evidence and provide a clearer understanding of how manipulative tools contribute to trigonometry learning.

Systematic Literature Review (SLR) offers a rigorous and transparent approach for synthesizing evidence through predefined search procedures, explicit inclusion criteria, and systematic quality appraisal (Page et al., 2021). By integrating findings across multiple studies, SLR enables researchers to identify patterns, evaluate the strength of available evidence, and formulate recommendations for educational practice and future research (Muka et al., 2020; De Cassai et al., 2023; Mengist et al., 2020). Therefore, this study aims to systematically synthesize empirical evidence concerning the use of manipulative tools in trigonometry education. Specifically, the review seeks to identify the types of manipulative tools employed in trigonometry learning, examine the extent to which manipulative-based interventions improve students' conceptual understanding compared with conventional instruction, analyse the methodological characteristics and quality of existing studies, identify contextual factors that may influence intervention effectiveness, and highlight practical implications and future research directions for trigonometry education.

METHODOLOGY

Research Design

This study employed a Systematic Literature Review (SLR) to synthesize empirical evidence on the use of manipulative tools in trigonometry education. The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines to ensure transparency, rigor, and reproducibility throughout the review process (Page et al., 2021). SLR was selected because it enables a comprehensive and systematic synthesis of findings from multiple studies, thereby providing a more reliable understanding of the effectiveness of manipulative-based interventions in trigonometry learning (Muka et al., 2020).

Search Strategy

A systematic search was conducted across four databases: Scopus, Web of Science, ERIC, and Google Scholar. Studies published between January 2020, and June 2025 were considered to capture recent developments in trigonometry education. The search strategy combined keywords related to trigonometry, manipulatives, and conceptual understanding using Boolean operators. Examples of search terms included: ("trigonometry" OR "trigonometric learning") AND ("manipulative tools" OR "physical manipulatives" OR "virtual manipulatives" OR "GeoGebra") AND ("conceptual understanding" OR "mathematics learning").

Eligibility Criteria

Studies were included if they met the following criteria:

1. Published between 2020 and 2025.
2. Written in English.
3. Empirical studies employing quantitative, qualitative, or mixed methods designs.

4. Investigated the use of physical or virtual manipulative tools in mathematics education, including studies directly related to trigonometry learning and studies providing transferable insights into conceptual understanding through manipulative-based instruction.
5. Reported outcomes related to conceptual understanding, achievement, engagement, reasoning, or learning performance.

Studies were excluded if they:

1. Were editorials, opinion papers, book reviews, or conference abstracts without full-text availability.
2. Did not examine manipulative, interactive, or representational tools relevant to conceptual understanding in mathematics learning.
3. Did not provide sufficient methodological information.
4. Examined purely technological interventions without manipulative or interactive representational components.

Given the limited number of empirical studies focusing exclusively on manipulative tools in trigonometry education, studies from broader mathematics learning contexts were also considered when they provided evidence relevant to conceptual understanding and manipulative-based instruction.

Study Selection Process

The study selection process followed the PRISMA 2020 framework. All retrieved records were exported into a reference management system and screened for duplicates. Subsequently, titles and abstracts were reviewed against the eligibility criteria. Full-text screening was then conducted to determine the final set of studies included in the review. Disagreements during the screening process were resolved through discussion until consensus was achieved among the reviewers.

Quality Assessment

To ensure the methodological rigor of the review, all included studies were critically appraised using established quality assessment instruments. Qualitative studies were evaluated using the Critical Appraisal Skills Program (CASP), whereas quantitative and quasi-experimental studies were assessed using the Joanna Briggs Institute (JBI) Critical Appraisal Tool. The appraisal process focused on research design, methodological transparency, data collection procedures, analytical rigor, and the credibility of reported findings. The results of the quality assessment are presented in [Table 1](#).

Table 1. Quality Assessment of Included Studies

No.	Author(s)	Research Design	Appraisal Tool	Quality Rating
1	Yaniawati et al. (2022)	Research and Development	JBI	High
2	Tang Minh Dung (2024)	Exploratory Intervention	JBI	High
3	Ferrerde et al. (2024)	Quasi-Experimental	JBI	High
4	Purnomo et al. (2025)	Design Thinking Study	CASP	Moderate
5	Niranjan & Brijlall (2025)	Case Study	CASP	High
6	Juandi et al. (2025)	Pedagogical Action Research	CASP	High
7	Qetrani et al. (2021)	Quasi-Experimental	JBI	High
8	Bungao-Abarquez (2020)	Quasi-Experimental	JBI	High
9	Fitri et al. (2024)	Qualitative Study	CASP	Moderate
10	Klu et al. (2023)	Quasi-Experimental	JBI	High

As shown in [Table 1](#), the majority of the included studies were classified as high quality, indicating that they demonstrated clear research objectives, appropriate methodologies, and sufficient evidence to support their conclusions. Two studies were rated as moderate quality because of limitations related to methodological reporting and the depth of data analysis. Nevertheless, all included studies met the minimum quality threshold established for this review and were therefore retained for synthesis.

Data Extraction and Synthesis

A standardized data extraction form was developed to ensure consistency in data collection. Information extracted from each study included author(s), publication year, country, educational level, research design, sample size, type of manipulative tool, intervention characteristics, outcome measures, and principal findings.

The extracted data were synthesized using thematic analysis. The synthesis process was guided by the objectives of the review and focused on identifying: (a) the types of manipulative tools used in trigonometry education, (b) the reported effects of manipulative-based interventions on students' conceptual understanding, (c) methodological characteristics of the included studies, (d) contextual and moderating factors influencing intervention effectiveness, and (e) implications for educational practice

and future research. Through iterative comparison of findings across studies, common themes, trends, and patterns were identified and organized according to the research objectives.

Table 2. Data Extraction Framework

Variable	Description
Author(s)	Study author(s)
Year	Publication year
Country	Research context
Educational Level	Primary, secondary, tertiary
Research Design	Quantitative, qualitative, mixed methods
Manipulative Type	Physical or virtual
Outcome Measures	Understanding, achievement, engagement
Main Findings	Principal results

RESULTS AND DISCUSSION

Study Selection Process

The study selection process was conducted following the PRISMA 2020 framework to ensure a transparent and systematic identification of relevant studies. The search strategy across the selected databases yielded an initial set of records related to manipulative tools in trigonometry education. After duplicate records were removed, the remaining studies were screened based on titles and abstracts according to the predefined eligibility criteria. Full-text articles were subsequently assessed for eligibility, resulting in the final set of studies included in this review. The detailed study selection process is presented in Figure 1.

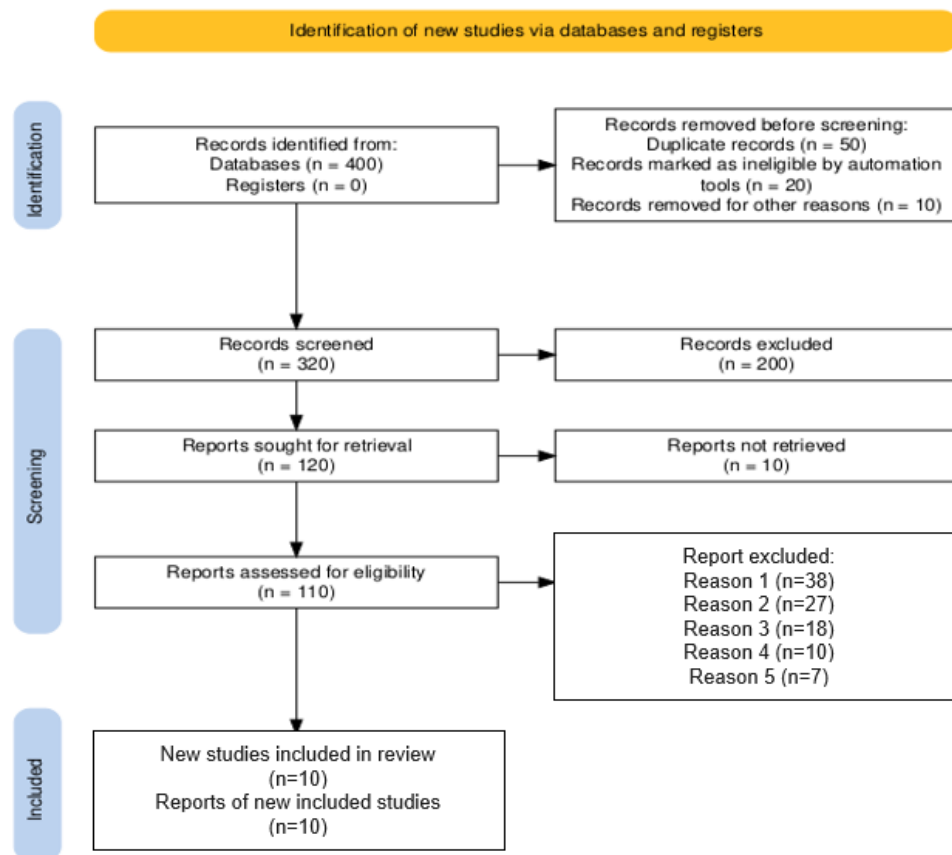


Figure 1. PRISMA 2020 Flow Diagram of Study Selection Process

As illustrated in Figure 1, the screening process substantially reduced the number of retrieved records through duplicate removal and eligibility assessment. Following the application of the inclusion and exclusion criteria, 10 studies were retained for final analysis. These studies formed the evidence base for examining the types of manipulative tools used in trigonometry education, their reported effects on student learning, methodological characteristics, and contextual factors influencing their effectiveness.

Overview of Included Studies

The final dataset consisted of 10 empirical studies published between 2020 and 2025 that investigated the use of manipulative tools in trigonometry education and related mathematics learning contexts. These studies were conducted across diverse educational settings and geographical regions, reflecting growing international interest in manipulative-based approaches to mathematics instruction.

The included studies employed a variety of research designs, including quasi-experimental, qualitative, case study, pedagogical action research, exploratory intervention, and research and development approaches. Among these, quasi-experimental designs were the most frequently adopted, indicating a strong emphasis on evaluating the effectiveness of manipulative-based interventions through measurable learning outcomes.

The reviewed studies also demonstrated considerable diversity in the types of manipulative tools employed. Some studies utilized physical manipulatives, such as geometric models and hands-on learning materials, whereas others implemented virtual manipulatives, including GeoGebra, Google Sheets, mobile learning platforms, and other technology-supported interactive environments. Despite these differences, all studies shared the common objective of enhancing students' conceptual understanding and mathematical learning through more interactive and learner-centered instructional approaches.

The characteristics of the included studies are summarized in Table 3. Although not all included studies focused exclusively on trigonometry, they were retained because they examined manipulative, interactive, or representational tools that contributed to conceptual understanding in mathematics learning and provided transferable insights relevant to trigonometry education.

Table 3. Summary of Relevant Studies on Mathematics and Trigonometry Learning

No.	Author(s)	Year	Research Design	Educational Focus	Manipulative Tool
1	Yaniawati et al.	2022	R&D	Trigonometry and Mathematical Connections	Mobile Learning Platform
2	Tang Minh Dung	2024	Exploratory Intervention	Sine Function Graphs	Google Sheets
3	Ferrerde et al.	2024	Quasi-Experimental	Trigonometric Conceptual Understanding	Contextual Mathematical Modeling
4	Purnomo et al.	2025	Design Thinking	Trigonometric Critical Thinking	Design-Based Learning Activities
5	Niranjana & Brijlall	2025	Case Study	Three-Dimensional Trigonometric Problems	Physical Manipulatives
6	Juandi et al.	2025	Pedagogical Action Research	Trigonometric Functions	GeoGebra
7	Qetrani et al.	2021	Quasi-Experimental	Mathematical Conceptual Understanding	Equivalence-Based Learning
8	Bungao-Abarquez	2020	Quasi-Experimental	Elementary Mathematics	Physical Manipulatives
9	Fitri et al.	2024	Qualitative	Trigonometric Identity Proofs	AI-Assisted Learning
10	Klu et al.	2023	Quasi-Experimental	Conceptual Understanding	Physical Manipulatives

Types of Manipulative Tools in Trigonometry Education

Analysis of the included studies revealed two major categories of manipulative tools employed in trigonometry education: physical manipulatives and virtual manipulatives. Physical manipulatives

included hands-on learning aids such as geometric models, trigonometric boards, cardboard constructions, and other tangible materials that enabled students to directly explore mathematical relationships. These tools were designed to support the visualization of trigonometric concepts and facilitate active learning through physical interaction (shown in Table 4).

Table 4. Classification of Manipulative Tools

Category	Studies	Examples
Physical Manipulatives	3	Geometric models, boards
Virtual Manipulatives	4	GeoGebra, Google Sheets
Hybrid/Interactive Approaches	3	M-learning, modeling activities

In contrast, virtual manipulatives included technology-supported tools such as GeoGebra, Google Sheets, mobile learning platforms, and other interactive digital environments. These tools provided dynamic visual representations that allowed students to manipulate variables, observe patterns, and explore relationships among trigonometric concepts in real time. Compared with physical manipulatives, virtual tools offered greater flexibility in presenting multiple representations, including symbolic, graphical, and geometric forms.

The reviewed studies suggest that both physical and virtual manipulatives serve a common instructional purpose: bridging the gap between abstract trigonometric concepts and students' conceptual understanding. While physical manipulatives were particularly effective for promoting concrete exploration and hands-on engagement, virtual manipulatives were frequently associated with enhanced visualization and dynamic conceptual exploration.

Effects of Manipulative Tools on Students' Learning

Across the reviewed studies, manipulative-based interventions were consistently associated with positive learning outcomes. The most frequently reported benefit was improved conceptual understanding of trigonometric concepts. Students demonstrated stronger abilities to interpret trigonometric relationships, connect multiple mathematical representations, and apply concepts in problem-solving situations after participating in manipulative-based learning activities.

Several studies also reported improvements in students' engagement, motivation, mathematical reasoning, and critical thinking skills. Manipulative tools appeared to encourage active participation by allowing learners to explore mathematical ideas through observation, experimentation, and discussion. Such experiences helped students construct knowledge more meaningfully compared with traditional lecture-based instruction.

Although positive outcomes were reported across most studies, the extent of improvement varied according to instructional design and implementation. The findings suggest that learning gains were influenced not only by the manipulative tools themselves but also by teacher facilitation, opportunities for reflection, and the integration of manipulatives into broader pedagogical strategies.

Methodological Characteristics of Included Studies

The methodological analysis revealed substantial diversity among the reviewed studies. Quasi-experimental designs were the most frequently employed research approach, reflecting a strong emphasis on evaluating intervention effectiveness through pre-test and post-test comparisons. Other methodologies included qualitative studies, case studies, pedagogical action research, exploratory interventions, and research and development approaches.

Most studies focused on measuring changes in students' conceptual understanding, achievement, and problem-solving performance. However, relatively few investigations explored long-term learning retention or examined how students construct conceptual understanding over extended periods. Furthermore, several studies were conducted within specific educational contexts and involved relatively small sample sizes, which may limit the generalizability of their findings.

These methodological patterns indicate that current research on manipulative-based learning in trigonometry remains dominated by short-term intervention studies. Future investigations may benefit from employing longitudinal and mixed methods designs to provide a more comprehensive understanding of how manipulative tools influence students' learning processes and outcomes.

Contextual and Moderating Factors

The effectiveness of manipulative-based interventions appeared to be influenced by several contextual factors. Educational level, intervention duration, teacher guidance, and the type of manipulative tool employed were among the most frequently reported variables affecting learning outcomes. Studies conducted over longer instructional periods generally reported stronger improvements in conceptual understanding than short-term interventions.

Teacher facilitation also emerged as an important factor. Manipulative tools were most effective when integrated into structured learning activities that encouraged inquiry, discussion, and reflection. Conversely, simply providing students with manipulatives did not automatically lead to improved understanding. The quality of instructional design played a critical role in determining whether students were able to meaningfully connect concrete experiences with abstract mathematical concepts.

In addition, differences between physical and virtual manipulatives were evident. Physical manipulatives tended to support hands-on exploration and concrete visualization, whereas virtual manipulatives provided opportunities for dynamic representation and immediate feedback. These findings suggest that the effectiveness of manipulative tools depends not only on the tool itself but also on how it is incorporated into the learning environment.

Implications for Practice and Future Research

The findings of this review highlight the educational value of manipulative tools in supporting trigonometry learning. Mathematics teachers are encouraged to integrate both physical and virtual manipulatives into classroom instruction to promote active learning, visualization, and conceptual understanding. Effective implementation should be accompanied by structured guidance, opportunities for discussion, and activities that encourage students to connect multiple mathematical representations.

For researchers, the review identifies several directions for future investigation. More longitudinal studies are needed to examine the sustainability of learning gains associated with manipulative-based interventions. Future research should also compare the relative effectiveness of physical and virtual manipulatives across different educational levels and learning contexts. Additionally, greater use of mixed-methods approaches would provide deeper insights into the cognitive processes through which manipulatives support conceptual development in trigonometry learning.

Overall, the reviewed evidence suggests that manipulative tools represent a promising instructional approach for enhancing trigonometry learning when integrated within carefully designed and pedagogically meaningful learning experiences.

CONCLUSION

This systematic literature review synthesized evidence from 10 studies published between 2020 and 2025 concerning the use of manipulative tools in trigonometry education. The findings indicate that both physical and virtual manipulatives have been employed to support students' learning of trigonometric concepts. Physical manipulatives primarily facilitate hands-on exploration and concrete visualization, whereas virtual manipulatives such as GeoGebra, Google Sheets, and mobile learning platforms provide dynamic representations that support conceptual understanding and mathematical reasoning.

Overall, the reviewed studies consistently reported positive effects of manipulative-based interventions on students' conceptual understanding, engagement, problem-solving ability, and mathematical reasoning. However, the effectiveness of these interventions was influenced by several contextual factors, including instructional design, teacher facilitation, intervention duration, and the type of manipulative tool employed. These findings suggest that manipulatives are most effective when integrated into well-structured learning environments that promote active exploration, discussion, and reflection.

This review contributes to the growing body of research on trigonometry education by providing a synthesis of current evidence regarding manipulative-based learning approaches. Nevertheless, the review is limited by the relatively small number of included studies and the focus on publications from 2020–2025. Future research should investigate the long-term effects of manipulative-based interventions, compare the relative effectiveness of physical and virtual manipulatives, and employ more diverse methodological approaches to better understand how manipulatives support conceptual development in trigonometry learning.

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