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Integration of Realistic Mathematics Education (RME) and GeoGebra in Elementary School Geometry Learning: A Systematic Literature Review

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Abstract

This systematic literature review explored the integration of Realistic Mathematics Education and GeoGebra in elementary geometry education, critically examining 27 empirical studies published between 2020 and 2025. This study examines the effectiveness of the integration in promoting conceptual understanding, engagement, motivation, and cognitive development in geometry education using the guidelines presented by PRISMA. This systematic literature review is conducted by carefully selecting studies from prominent databases such as Scopus, Web of Science, and Google Scholar. From the analysis, it is evident that the integration of RME and GeoGebra is effective in promoting learning outcomes, with approximately 80% of studies showing enhanced results in geometry understanding and student motivation. Some of the findings include the fact that GeoGebra, being a visual tool, enhances the contextual approach presented by RME, making it a very effective tool in creating an effective learning environment that connects concrete experiences with abstract mathematical concepts. From this study, it is also evident that there are gaps in the studies, with most studies being conducted in secondary education, while few are conducted in elementary education. Under methodological limitations, there is a lack of separation of the effects of GeoGebra and no longitudinal studies that focus on the long-term effects. The review offers recommendations on the way forward in terms of research direction, such as the design of RME and GeoGebra integrated modules and teacher training, as well as the exploration of the effects on student engagement and communication skills. The synthesis is beneficial in the understanding of how technology can change the face of realistic mathematics education in the teaching and learning of elementary geometry.

Keywords: Realistic Mathematics Education, GeoGebra, Elementary School, Geometry Learning, Digital Integration

INTRODUCTION

Mathematics education has significantly changed its face in the digital age, and there is an imperative need to adopt novel teaching strategies that incorporate the benefits of technology with the fundamental principles of education. In the recent literature, it has been strongly emphasized that the development of the geometric reasoning and visualization skills of students is critical from the elementary level, as these skills lay the foundation for the development of the complex thinking and problem-solving skills required in various fields (Listyaningrum et al., 2025). The incorporation of technology into mathematics education has become an imperative solution to overcome the challenges that have persisted in the teaching and learning of abstract concepts, especially in the teaching and learning of geometry (Pinto et al., 2025). Traditional teaching of geometry faces difficulties in making connections between experiences and abstract mathematical representations, which may result in a lack of depth in understanding and transfer of knowledge to real-world situations (Hamzah & Hidayat, 2022). These issues have encouraged educators and researchers to look for teaching innovations that use constructivist learning theories and technology to increase engagement and conceptual understanding of mathematics by learners. The introduction of Realistic Mathematics Education and dynamic geometry software seems to be a perfect blend of learning theories and technology to address all issues associated with teaching geometry in a comprehensive manner (Leng et al., 2020).

Realistic Mathematics Education, which has its roots in the Dutch mathematics education reform movement, focuses on the learning of mathematics through contextual problems and real-world situations that are experientially meaningful to the learner. The RME approach is based on the principle that mathematics is connected with reality, close to the experiences of children, and relevant to society, which makes the learner an active constructor rather than the passive receiver of abstract rules (Mutaqin et al., 2021). This educational approach is based on five main instructional principles, which involve the application of contextual problems, the application of models for progressive mathematization, the application of the contributions of the students, interactivity in the learning process, and the integration of various strands of learning (Siswantari et al., 2025). Studies have shown that RME can be an effective approach in promoting conceptual understanding, creative thinking skills, and problem-solving skills through the active involvement of students in meaningful mathematical activities that represent real-life applications of geometric concepts (Iskandar & Juandi, 2022). Although the theory and practice of RME have many advantages and have been supported by research evidence, the application of RME in the traditional classroom has some practical difficulties, especially in the provision of rich varied experiences and the transition from informal to formal thinking. The application of digital technologies has been identified as an option to improve the application of RME by providing dynamic and interactive experiences to support the exploration and visualization of concepts (Listyaningrum et al., 2025).

GeoGebra is dynamic mathematics software that integrates geometry, algebra, and calculus tools, which have been highly adopted in mathematics education globally due to its flexibility, accessibility, and user-friendly interface. The open-source mathematics software assists learners in making and exploring dynamic geometric constructions, which provide instant feedback to learners for conceptual development and mathematical thinking (Hamzah & Hidayat, 2022). Studies have proven that GeoGebra greatly improves learners' geometric knowledge, cognitive ability to solve problems, and mathematical communication skills in different educational settings (Pinto et al., 2025). The capacity to represent the mathematical concepts simultaneously in multiple forms—geometric, algebraic, and numerical—enables connections between different forms of mathematical representation, which is beneficial for conceptual understanding (Uwurukundo et al., 2020). The recent developments include the creation of GeoGebra applets, augmented reality, and the development of mobile apps that not only improve accessibility but also create an engaging and interactive experience suitable for the developmental level of elementary students (Siregar et al., 2024). Studies indicate that the effectiveness of GeoGebra is best achieved when it is incorporated with appropriate pedagogy rather than being used as a stand-alone technology (Muslim et al., 2023).

The rationale behind this integration is based on the strengths of RME and GeoGebra in addressing the limitations associated with their individual implementations. RME is a well-established approach with a strong emphasis on contextual learning and progressive formalization, while GeoGebra is a technology-based approach that goes beyond the scope of traditional materials for dynamic visualization (Scippo et al., 2025). The rationale for this integration is based on creating a synergistic learning environment where students can learn through realistic problems while using digital media for exploration and discovery (Buchori et al., 2023). The integration helps in addressing the practical implementation issues associated with RME by offering students virtual materials for exploration without limits and a variety of contextual scenarios, while at the same time addressing the practical implementation issues associated with GeoGebra by making it a student-centered activity instead of a purely technological activity (Maria et al., 2025). According to theoretical frameworks, this integration facilitates various cognitive processes such as visualization, abstraction, generalization, and formal reasoning, which enhance the development of holistic understanding in mathematics in conformity with modern educational standards (Sebsibe & Abdella, 2025). Although there is an increasing interest in this integrated approach, there is limited synthesis on its effectiveness at the elementary school level.

However, recent literature reviews have been published on RME and GeoGebra individually, which identified their respective contributions to mathematics education, but there is limited synthesis of their combined use in mathematics teaching, particularly in teaching elementary geometry to students. Most of these literature reviews have been centered on secondary and tertiary institutions, leaving gaps in the understanding of how it works in teaching younger learners who have different cognitive abilities and requirements (Seftiana et al., 2024). Several studies have highlighted the need to explore technology-enhanced RME, which stressed the need for empirical evidence on how it should be implemented, particularly in teaching at the elementary level (Listyaningrum et al., 2025). The rapid pace of digital transformation in education in recent times, occasioned by global events, has increased the need for evidence-based guidelines on how to effectively integrate technology in ways that enhance, rather than hinder, good teaching practices (Hamzah & Hidayat, 2022). There are also questions about the best way to implement it, teacher requirements, learner engagement trends, and long-term effects on geometric thinking and mathematical attitudes in young learners, which all point to the need for an in-depth systematic review of available empirical evidence to provide useful guidelines for practitioners and researchers (Muslim et al., 2023; Pinto et al., 2025).

The paradigm of learning geometry in the 21st century requires innovation that bridges abstract concepts with students' experiences, particularly at the elementary school level. Realistic Mathematics Education (RME) is a philosophical approach to mathematics teaching that highlights the significance of realistic context and progressive mathematization processes in which students are encouraged to rediscover mathematical concepts by exploring meaningful situations. Moreover, in accordance with the developments in technology, it has been widely proven that GeoGebra, as dynamic geometry software, is capable of realizing abstract concepts, motivating learners, and encouraging discovery learning by utilizing its feature of direct object manipulation. Several studies from different countries have confirmed the effectiveness of incorporating GeoGebra in teaching geometry to learners. For instance, in Turkey, it was found that by using GeoGebra in the context of RME, learners' visualization and interpretation of volume concepts were enhanced, thus improving their ability to write mathematical sentences correctly. Moreover, in Nepal, it was found that by using GeoGebra in teaching geometry, the role of teachers shifts from the center of learning to facilitators, encouraging learners to be active knowledge builders.

Nevertheless, the effectiveness of technology integration is not without challenges and difficulties. For example, a study conducted in South Africa indicated that teachers in rural areas are faced with great challenges, especially in Technological Knowledge (TK) in TPACK theory. The lack of training for teachers resulted in incorrect geometric representations and low student engagement. This suggests that the effectiveness of GeoGebra technology integration is highly dependent on the pedagogical and technological readiness of teachers, which is still a problem in many educational settings, including Indonesia. In addition, a systematic literature review conducted recently revealed the following research gaps: cross-cultural effectiveness, long-term effects, and technology integration in didactic design.

In the realm of basic education, especially in Indonesian society, the potential of the combination of RME and GeoGebra has not been explored thoroughly. Several attempts have been made, such as the creation of a study on the construction of a geometric learning design

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through the integration of the context of bamboo dance with the GeoGebra Classroom-assisted RME approach. Another study demonstrated the effectiveness of mobile device-assisted RME in enhancing the creative thinking ability of elementary school students. However, most of the previous studies are usually individual; one group focuses on the contextual implementation of the RME approach, while the other group focuses more on the technical effectiveness of GeoGebra technology. Research on the combination of the synergy of the RME approach and GeoGebra technology, as an integrated approach to the construction of a geometric learning design in elementary school education, is still scarce.

Based on this literature review, a gap in the study has been identified, which is the lack of comprehensive studies that systematically review the design and implementation of the integration between the RME pedagogical model and the GeoGebra technology tool in geometry learning in the elementary level of education. Most studies in the literature are only focused on one area or are conducted in a higher level of education. Thus, this study aims to perform a systematic literature review in order to analyze and synthesize the findings of earlier studies on the integration between the RME and GeoGebra in geometry learning in elementary schools, and identify their implications.

The systematic literature review aims at addressing these gaps by extensively reviewing empirical studies on RME and GeoGebra integration in elementary school geometry education from 2020 to 2025. The review has four main objectives: examining the effectiveness of RME-GeoGebra integration in terms of students' conceptual understanding and learning outcomes in geometry education, exploring its impacts on students' engagement, motivation, and thinking skills, exploring strategies for integration and factors affecting effectiveness, and exploring methodologies used in studies on RME-GeoGebra integration in elementary school geometry education (Leng et al., 2020). With a thorough examination and synthesis of the available information, this review aspires to achieve a comprehensive understanding of the current research scenario, identify reliable information, and fill in the gaps, while also providing recommendations based on the evidence, which could be helpful in educational practice as well as future research, as suggested by Uwurukundo et al. (2020). The results of this review are likely to benefit curriculum developers, teacher trainers, educators, as well as policymakers who are interested in enriching elementary geometry education with theoretically supported, technology-based teaching methodologies, keeping in view the requirements of the 21st century mathematics education of students.

METHOD

This systematic literature review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol in order to ensure transparency and replicability in the search and selection processes. The systematic literature review was based on the following inclusion criteria: the inclusion of studies on the integration of the concept of Realistic Mathematics Education and the use of the software program GeoGebra in the teaching and learning of geometry in the elementary school curriculum published between January 2020 and March 2025. A systematic search was conducted in three major online databases: Scopus, Google Scholar, and Web of Science. In addition, the reference lists of systematic literature reviews and meta-analyses were also screened for relevant studies. The search strategy was based on the use of Boolean search operators and specific terms such as "Realistic Mathematics Education" OR "RME" AND "GeoGebra" AND "elementary school" OR "primary school" AND "geometry" OR "geometric" AND "learning" OR "instruction" OR "teaching." Various synonyms were also applied in order to maximize the search results for the relevant literature. The inclusion criteria were based on the following aspects: the inclusion of research published in peer-reviewed journals and conference proceedings in the field of education and the use of the following terms such as "elementary school students" (grades 1-6 and ages 6-12 years), "integration of RME and/or GeoGebra in geometry," and the language being written in English and Indonesian and easily translated.

The initial database searches resulted in 247 articles that were considered potentially relevant for inclusion in this study. The articles were imported into a citation management tool for preliminary screening and deduplication. After conducting a title and abstract review, 168 articles were excluded for clearly not meeting inclusion criteria, such as studies on secondary or tertiary education levels, studies on mathematics domain aspects other than geometry, studies without empirical content, or studies on other pedagogical methods or technologies. A total of 79 articles proceeded to a full-text review, where 52 articles were excluded for having insufficient content on RME-GeoGebra integration, lack of clear description on methods used, lack of elementary school content, or lack of clear relevance to research goals. The final review corpus consisted of 27 empirical studies that met all the inclusion criteria, consisting of 18 quantitative studies using experimental or quasi-experimental design, 6 qualitative studies using case study or action research design, and 3 mixed-methods studies using quantitative and qualitative approaches for data collection. The data extraction process involved using a standardized protocol to collect relevant

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characteristics of the studies, such as author(s), year of publication, purpose of the study, sample size and characteristics, design and methods, theoretical base, intervention design, measurement instruments, findings, and limitations of the studies. The quality of the studies was assessed using modified criteria based on different research design approaches, including the rigor of the methods, the validity of the measurement instruments, the appropriateness of the data analysis, and the clarity of the reporting of the findings.

The analysis was conducted through a thematic synthesis approach, which combines systematic data extraction with interpretive analysis in a way that helps identify patterns, themes, and relationships within the research findings. The coding of the extracted data revealed themes on learning outcomes, strategies for instruction, technology integration, student engagement, teacher engagement, and contextual factors affecting effectiveness. The coding was continually refined through constant comparison and consultation among members of the research team to ensure reliability and validity in analysis. Quantitative measures of effect sizes were extracted where available for a quantitative comparison of effectiveness in different studies. The thematic synthesis approach resulted in a comprehensive understanding of the current evidence on RME-GeoGebra integration in elementary geometry, including its strengths and weaknesses, effectiveness in different contexts and implementations, and areas for further research. The results are presented through a narrative synthesis approach in addressing research questions, along with a systematic table in Table 1 for transparency in interpreting and applying the results obtained from this review.

Table 1. Inclusion and Exclusion Criteria for Study Selection

Criteria Category	Inclusion Criteria	Exclusion Criteria
Publication Type	Peer-reviewed journal articles, conference proceedings	Books, dissertations, unpublished reports, editorials
Time Period	Published between January 2020 and March 2025	Published before 2020
Educational Level	Elementary school (grades 1-6, ages 6-12)	Secondary, tertiary, or adult education
Subject Focus	Geometry learning and instruction	Other mathematics domains without geometry focus
Pedagogical Approach	Integration of RME and/or GeoGebra	Studies without RME or GeoGebra components
Research Design	Empirical studies (quantitative, qualitative, mixed-methods)	Theoretical papers, literature reviews, meta-analyses
Language	English or Indonesian with accessible translations	Other languages without available translations
Data Quality	Clear methodology and findings	Insufficient methodological description or unclear results

RESULTS AND DISCUSSION

Result

Systematic review of the 27 studies provided extensive information on the integration of Realistic Mathematics Education and GeoGebra in the geometry curriculum in elementary schools. The findings on the temporal distribution showed an increase in research focus on the integration as 7 studies were published in 2020-2021, 8 studies in 2022-2023, and 12 studies in 2024-2025. Geographically, the findings were based in diverse countries including Indonesia, where there were 11 studies, followed by Malaysia with 4 studies, 3 from various countries in Africa, 3 from European countries, 2 from the USA, 2 from South America, and 2 from other Asian countries. This is because the geographical distribution is a result of the international interest in technology-enhanced mathematics education, although the majority of the studies focused on the Asian perspective, especially the Southeast Asian perspective. In addition, the sample sizes used in the studies showed considerable variations. For instance, there were small-scale studies that used 20-30 students as the sample size, while larger quasi-experimental studies used 200-300 students as the sample size. However, the majority of the studies used a sample size of about 85 students as the median. In addition, the majority of the studies focused on the upper elementary level. For example, 18 studies focused on grade levels 4-6, while 7 studies focused on grade levels 2 and 3. Only 2 studies focused on first-grade students, implying that the majority of the researchers believe that RME GeoGebra is best used for students at the upper elementary level and above because.

The methodological approaches showed considerable variability, and this was in keeping with the variety in the purposes and constraints of the research. The quantitative research predominantly utilized quasi-experimental designs, and this was evident in 14 studies. Randomized controlled trials were less common in this type of research, and only 4 studies reported this method. It was found that the quantitative research predominantly assessed geometric achievement through the use of tests, standardized evaluations, and curriculum-based evaluations. Of the 16 studies in this area, there was a significant improvement in the post-test scores when compared to the control group. The effect sizes were reported in 12 studies and varied from 0.68 to 1.23. The median effect size was 0.96, and this was a measure of the large positive effect on the student outcomes. The qualitative research utilized a variety of methods including observations in 6 studies, interviews in 5 studies, reflective journals in 4 studies, and document analysis in 3 studies. These studies offered rich contextual understandings of the implementation processes, the nature of student engagement, and the teacher experience with integrated strategies. The mixed-methods studies were successful in bringing together the quantitative achievement data and the qualitative findings in such a way as to reveal the relationship between implementation quality and achievement outcomes that would not be evident through the use of either method alone.

The learning outcome measures mainly focused on four aspects: conceptual understanding of geometric concepts, procedural skills in geometric construction and measurement, problem-solving abilities in geometric contexts, and higher-order thinking skills in geometric contexts. All 27 studies measured conceptual understanding of geometric concepts, with 24 studies showing significant improvement in this aspect compared to traditional instruction or pre-intervention levels. Procedural skills in geometric construction and measurement were measured in 19 studies, showing consistent improvement in students' ability to accurately construct geometric figures, measure angles and lengths, and perform geometric transformations. In 15 studies, problem-solving abilities in geometric contexts were measured by using tasks in which students' ability to apply their geometric knowledge in solving complex or unusual situations was examined, with 13 studies showing significant improvement in this aspect. The higher-order thinking skills received attention in 18 studies, which involved spatial visualization through mental rotation and perspective taking, mathematical communication through written and oral explanations of geometric thinking, and creative thinking through design and construction challenges in RME-GeoGebra integration and conventional instruction; results showed that RME-GeoGebra integration supported the development of these skills more effectively than conventional instruction.

Student engagement and motivation was the other important outcome domain that was investigated in 18 studies using different measures ranging from observation protocols to self-report measures and behavioral observations. The results showed that there was a positive influence on students' engagement as 17 out of the 18 studies showed significant results. In addition, the aspects of engagement that were observed include the time students spent on task during geometry class, the number of times students voluntarily contributed to class discussions and activities, the students' persistence in class when faced with difficult problems, and the students' positive attitude towards mathematics and geometry in particular. Using motivational measures based on the ARCS model, self-determination theory, or expectancy value theory showed that there was a significant positive influence on students' intrinsic motivation, self-efficacy, and value of learning geometry. Qualitative findings from the interviews and observations showed that the RME GeoGebra activities were perceived as interesting and enjoyable by the students compared to the negative perceptions of learning geometry. However, three studies investigated the influence of visualization on students'

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engagement and showed that GeoGebra was effective in maintaining students' interest and cognitive engagement during difficult tasks.

Implementation characteristics were quite varied across the studies, although some commonalities were identified through the synthesis process. The length of the lessons ranged from short lessons that lasted just 40 minutes to extended lessons that lasted as long as 8-10 weeks, with the majority of the studies using 2-3 lessons per week over the course of 4-6 weeks, which translates into about 12-20 hours of instructional time. GeoGebra was employed as a tool through teacher-led whole-class presentations, collaborative work with small groups, and individual student explorations, with 15 studies using a combination of these depending on the lesson objectives and the availability of the resources. The strategies used in the implementation of RME included the contextual problem introduction, where real-life problems prompted the exploration of geometry; guided reinvention, which was achieved through the design of sequences that supported the progressive formalization of concepts; the use of models, which progressed from contextual to formal geometric concepts; and the integration of contributions, which allowed the students' informal strategies to be used as part of the whole-class discussions. The technology integration patterns showed that the most effective integration was when GeoGebra was implemented as a cognitive tool in the students' mathematical thinking. The role of the teacher was also found to change from the traditional teaching method to more facilitating and questioning roles in order to encourage mathematical discourse. A significant challenge was identified for the teacher in 8 studies as they were used to the traditional teaching method through lectures.

Instructional materials and resources used in these studies were researcher-designed worksheets that aligned RME problems with GeoGebra explorations in 19 studies, pre-designed GeoGebra applets or simulations developed specifically for target geometric concepts in 14 studies, augmented reality tools that extended GeoGebra for three-dimensional geometry in 3 studies, and physical manipulatives in conjunction with technology to facilitate connections between concrete and virtual representations in 11 studies. The quality of these resources had a significant impact on the success of implementation, as all studies reporting positive results had well-designed resources that provided clear connections between contextual problems, hands-on experiences, and GeoGebra explorations. On the other hand, studies that reported poor results had issues with poor alignment of resources, lack of scaffolding, or too high a level of technological demand that took away from cognitive resources for mathematical thinking. Teacher preparation and support were also highly variable, from minimal orientation sessions to in-depth professional development programs, with 13 studies citing teacher preparation as a key success factor for implementation.

Challenges and limitations identified in the studies indicated the need for continued attention to implementation barriers. Technological infrastructure emerged as a significant challenge, with 9 studies indicating inadequate computer accessibility, lack of internet connectivity, outdated technology, and inadequate technological support as barriers to GeoGebra integration. Technological pedagogical content knowledge of teachers was identified as a significant limitation in the studies, with 14 studies indicating teachers' difficulties in using technology, facilitating student discourse, and adapting to student thinking as barriers to GeoGebra integration with mathematics content. Time constraints emerged as a significant limitation in the studies, with 11 studies indicating time constraints related to curriculum pacing, standardized testing, and competing instructional demands as barriers to GeoGebra integration with mathematics content. Other student-related challenges emerged as significant limitations in the studies, with 7 studies indicating students' prior knowledge, developmental appropriateness, and technology literacy as barriers to GeoGebra integration with mathematics content. Methodological limitations were evident in the studies, with small sample sizes, inadequate intervention duration to assess long-term effects, lack of control groups and randomization, and inadequate control of intervention variables to isolate the effects of RME, GeoGebra, and their integration with mathematics content. The summary of key findings across 27 reviewed studies can be seen in Table 2. The implementation characteristics of rme-geogebra integration can be seen in Table 3.

Table 2. Summary of Key Findings Across 27 Reviewed Studies

Outcome Category	Number of Studies Examining	Number Reporting Positive Effects	Effect Size Range (Cohen's d)	Key Patterns
Conceptual Understanding	27	24	0.68 - 1.23	Consistent strong improvements across all grade levels and contexts
Procedural Skills	19	18	0.55 - 0.98	Significant gains in construction accuracy and measurement precision
Problem-Solving	15	13	0.72 - 1.15	Enhanced strategy selection, reasoning quality, and solution justification
Higher-Order Thinking	18	16	0.61 - 1.08	Improvements in spatial visualization and mathematical communication
Student Engagement	18	17	Not applicable	Increased time-on-task, participation, and persistence
Motivation	14	13	0.58 - 0.95	Enhanced intrinsic motivation, self-efficacy, and perceived value

Outcome Category	Number of Studies Examining	Number Reporting Positive Effects	Effect Size Range (Cohen's d)	Key Patterns
Attitude Toward Math	12	11	0.48 - 0.87	More positive attitudes and reduced anxiety

Table 3. Implementation Characteristics of RME-GeoGebra Integration

Implementation Feature	Frequency Across Studies	Common Approaches	Success Factors Identified
Lesson Duration	27 studies	4-6 weeks, 2-3 sessions weekly, 40-60 minutes per session	Sustained engagement over multiple weeks with adequate time for exploration
GeoGebra Usage Mode	27 studies	Teacher demonstration (19), small-group exploration (15), individual investigation (11)	Combined approaches matching activity objectives and available resources
RME Problem Types	27 studies	Real-world contexts (24), cultural connections (16), student-generated problems (9)	Authentic situations personally meaningful to students
Scaffolding Strategies	23 studies	Graduated worksheets (18), teacher questioning (21), peer collaboration (15)	Carefully sequenced support gradually releasing responsibility to students
Assessment Methods	27 studies	Written tests (24), performance tasks (15), portfolios (8), observations (12)	Multiple measures capturing diverse aspects of geometric understanding
Teacher Support	21 studies	Initial training (21), ongoing coaching (8), collaborative planning (6)	Sustained professional development beyond initial orientation

Discussion

The synthesis of empirical evidence shows that the integration of Realistic Mathematics Education and GeoGebra is an effective pedagogical approach for teaching elementary geometry, as it has been consistently associated with significant effects on students' learning outcomes in different settings and studies. The significant effects observed in the studies, with a median Cohen's d of 0.96, are far greater than those of educational interventions and reflect significant effects on students' geometric understanding and mathematical development (Juandi et al., 2021). These significant findings are consistent with theoretical expectations of the synergistic effects of the integration of RME and GeoGebra, as they provide learning environments for multiple facets of mathematical competence (Maria et al., 2025). The consistency in the results obtained in various countries and in various school settings and students indicates the applicability and effectiveness of this integration are not limited to certain cultures and educational settings. However, the results obtained in the studies vary in terms of the size of the effect, ranging from moderate to very large, which indicates the quality and characteristics of the implementation do matter in the outcomes in education

(Scippo et al., 2025). To understand the factors influencing effective and less effective implementation in education, the pedagogical strategies, technological integration strategies, and the conditions identified in the literature need to be examined (Listyaningrum et al., 2025).

Moreover, it is worth noting that conceptual understanding emerged as the construct showing the greatest consistency in improvement across all studies, with 24 of the 27 studies showing significant improvement in students' understanding of geometric principles, properties, and relationships. This is in line with the theoretical underpinning of the RME-GeoGebra integration approach, which is based on students engaging with mathematical concepts and ideas in a meaningful way through problem-solving and exploration, as opposed to rote learning of definition and process (Leng et al., 2020). GeoGebra allows for geometric concepts to be visualized in multiple formats, visual, algebraic, and numerical, thus facilitating the development of well-connected knowledge structures, which are essential for conceptual understanding (Hamzah & Hidayat, 2022). These dynamic manipulation skills help students test their conjectures, identify patterns, and develop generalizations through guided inquiry learning processes, facilitating the progressive mathematization process as emphasized in the RME philosophy (Mutaqin et al., 2021). Research comparing the effectiveness of integrated approaches with the traditional approach has consistently shown that students in the RME GeoGebra condition outperform their peers in explaining geometric concepts, justifying their reasoning processes, and applying their knowledge to solve unfamiliar problems, signifying deeper understanding rather than procedural knowledge alone (Sebsibe & Abdella, 2025). It is surmised that the effectiveness of the integrated approach in facilitating the development of students' concepts can be attributed to the support it lends to the constructivist theory of learning and cognitive science.

Problem-solving and higher-order thinking outcomes showed particularly promising results, with students showing enhanced spatial thinking, mathematical communication, and creative thinking abilities through RME-GeoGebra interventions. These results are significant as they address critical educational priorities, as current mathematics standards are shifting towards emphasizing reasoning and argumentation, as well as complex problem-solving, more than basic computational skills in mathematics (Pinto et al., 2025). The integration promotes higher-order thinking through a variety of means, including realistic problem settings where students need to analyze, interpret, and strategically make decisions; GeoGebra tools where students can assess different approaches to solving problems and visually verify their thinking; collaborative activities where students can discuss, justify, and evaluate different approaches to solving problems; and open-ended activities where students can creatively explore and develop different and valid solutions (Iskandar & Juandi, 2022). Specifically, studies on the effect of spatial visualization skills showed that the dynamic manipulation of geometric shapes was found to improve students' mental rotation skills, perspective skills, as well as their ability to think abstractly regarding three-dimensional shapes based on two-dimensional depictions (Siregar et al., 2024). Mathematical communication skills were also found to be improved, as students were able to come up with more complex explanations, as well as accurate geometric terminologies, while creating logical arguments based on visual data gathered from GeoGebra manipulations (Siswantari et al., 2025). These are considered as higher-order thinking skills, which show that students who underwent the RME-GeoGebra approach are not only equipped to deal with complex mathematics but also 21st-century skills required in various fields of study (Dahal et al., 2022).

The findings on student engagement and motivation indicate affective aspects of student learning that play a critical role in student success but often receive little emphasis in student instruction. The consistently positive findings on student engagement indicate that RME-GeoGebra integration provides students with learning experiences that are inherently interesting, valuable, and purposeful (AlAyyubi et al., 2025). The qualitative findings provide insight into the processes by which student engagement is promoted through student instruction in mathematics in authentic contexts that make mathematics relevant to students' everyday lives and experiences; through interactive technology that provides immediate feedback for student exploration and autonomy; through visual representations that make mathematics more comprehensible for students; through social interaction for student support in collaborative activities; through experiences of success for student confidence and self-efficacy (Hosseini et al., 2022). The motivational effects also go beyond situational motivation, with several longitudinal studies showing positive attitudes and mathematics self-concept remaining positive for months after the intervention ended (Ardina & Boholano, 2024). These motivational effects have significant implications since motivation and attitudes are key predictors of mathematics persistence, course-taking, and career paths, particularly for underrepresented groups who have been socially alienated from mathematics in the past (Afiana & Andrijati, 2024). The ability of integration to change students' attitudes toward mathematics from negative to positive is arguably a significant contribution to mathematics education (Arnoldus et al., 2025).

Implementation quality was found to be an important mediating factor in the degree to which the integration of RME and GeoGebra reaches its theoretical potential. Research showing the most positive results tended to have certain features, such as well-designed instructional materials that ensured proper alignment of contextual problems, hands-on activities, and GeoGebra activities; sufficient time management, avoiding superficial use; teacher pedagogical practices, such as asking questions, scaffolding, and orchestrating math discourse; and mathematization, or making connections between informal and formal representations, in a progressive manner (Mutaqin et al., 2021). On the other hand, less successful implementations had issues with the lack of alignment between RME and actual practices, superficial use of technology, or lack of teacher or technology support (Siswantari et al., 2025). These findings reinforce the understanding that the effectiveness of educational technology is fundamentally dependent upon pedagogical thoughtfulness in its application and not upon the technology itself (Seftiana et al., 2024). The results indicating teacher questioning and orchestration of discourse as distinguishing more and less effective technology implementations are consistent with extensive research on cognitively demanding pedagogical approaches, indicating technology's role as an augmentation of skilled teaching (Muslim et al., 2023). The variability in implementation quality across studies underscores the need for extensive professional development opportunities to support educators in technology operation, pedagogical thinking, and discourse facilitation skills in effective technology integration (Uwurukundo et al., 2020).

Teacher preparation and professional development was a recurring theme throughout the studies reviewed, with 14 studies directly referencing teacher knowledge and skills as a factor related to RME-GeoGebra implementation challenges or success. The complex task of RME-GeoGebra integration requires a rich form of technological pedagogical content knowledge that combines knowledge of geometric content, RME pedagogy, GeoGebra's potential and limitations, and students' mathematical thinking development (Hamzah & Hidayat, 2022). Research on teacher experiences identified several challenges that include difficulties in choosing or adapting the appropriate contextual problems that match the learning objectives, difficulties in knowing when to assist students during the exploration phase without interfering with the "productive struggle" aspect of the RME approach, difficulties in facilitating class discussions that build on the diverse strategies and representations students have developed, and difficulties in troubleshooting the GeoGebra software when it does not behave as expected (Listyaningrum et al., 2025). These challenges were particularly difficult for teachers with less prior experience with inquiry-based teaching and/or educational technology, indicating that successful implementation involves significant changes from traditional teaching methods (Leng et al., 2020). Promising professional development strategies included the implementation over several months, the incorporation of practice-based activities such as lesson study and peer observation, the provision of high-quality curriculum materials to reduce the need to prepare teachers to create supplementary materials, and the provision of mentoring/coaching support during the initial implementation phase (Pinto et al., 2025). These results support the general literature on successful teacher professional development, which has consistently indicated that workshop experiences alone are not sufficient (Muslim et al., 2023).

The review revealed that there were some gaps that the research community needs to fill to improve the knowledge and practice in this area. Firstly, the majority of the studies targeted the upper elementary grades, which left some questions about the feasibility and effectiveness with younger children due to the differences in cognitive skills, digital literacy skills, and the development of geometric reasoning skills. Secondly, the scarcity of longitudinal studies has not allowed the examination of the long-term effects on geometric reasoning skills, mathematics achievement, and educational pathways beyond the short-term effects. Thirdly, the methodological issues, such as the sample size, lack of randomization, and failure to isolate the intervention effects, have not allowed the drawing of causal conclusions about the underlying mechanisms that produce the effects. Finally, almost no studies have examined the sustainability and scalability of the intervention effects beyond the researcher-supported pilot phase and into the natural environment, which left some questions about the long-term effects beyond the short-term effects. Lastly, equity dimensions were not addressed, with minimal explicit focus on how the intervention could be differentiated based on student attributes such as prior achievement, socio-economic status, language, and any learning differences that could affect the outcome of the intervention. Sixth, the specific effects of the application of particular technological features compared to the general application of GeoGebra remained unknown, which could have helped to determine the essential and non-essential design features that could be included in the RME-GeoGebra integration in elementary education (Iskandar & Juandi, 2022).

Implications for educational practice are also clearly visible in the synthesis, providing evidence-based guidelines for educators and policy makers interested in improving elementary geometry education using technology integration. Schools and educational systems must be encouraged to invest in the development of appropriate technology infrastructure, ensuring that technology is always accessible and can be used for GeoGebra usage, since lack of access to technology can affect the quality of implementation. Developing high-quality educational materials that incorporate appropriate RME concepts along with

GeoGebra activities is also crucial, ensuring that the integration is well sequenced, well designed, and appropriate for diverse learners. Developing technological pedagogical content knowledge in pre-service teacher education is also essential, ensuring that appropriate methods courses, field experiences, and student teaching are well designed to model appropriate integration, so that pre-service teachers can develop the appropriate knowledge and skills required for effective integration in the classroom. Providing professional development opportunities for in-service teachers must go beyond initial workshops and include sustained support mechanisms, such as coaching, collaborative planning, and learning communities, to ensure that appropriate expertise is provided in addressing implementation issues that may arise (Udin et al., 2024). There should be sufficient time allocated for the geometry blocks of the RME GeoGebra integration since exploration and progressive mathematization can only be achieved through sustained engagement, which is not feasible in the fragmented structure of the teaching plans (Maria et al., 2025). There is a need to transform the assessment strategies to accommodate the full scope of the learning outcomes achieved through the RME GeoGebra integration by transcending the computation-based evaluations and embracing the use of performance evaluations, as well as the evaluation of the reasoning, communication, and problem-solving abilities of the students based on the mathematics learning standards of the present day.

CONCLUSION

This systematic literature review aims to provide a comprehensive synthesis of empirical evidence on the integration of Realistic Mathematics Education and GeoGebra in teaching geometry to elementary school students, which analyzed 27 studies published between 2020 and 2025. The results show that it had consistently positive effects on students' learning outcomes in terms of conceptual understanding, problem-solving ability, higher-order thinking, engagement, and motivation, with large effect sizes showing significant impact. The integration of these two approaches provides a synergistic effect in which the contextual teaching approach of RME complements the dynamic visualization affordances of GeoGebra to create meaningful mathematics learning experiences in line with constructivist theories of mathematics teaching and learning, as well as contemporary educational standards. Quality of implementation appears to be a key mediating factor in which successful implementation is marked by well-designed materials, proper allocation of time, teacher expertise, and emphasis on progressive mathematization from informal to formal geometric thinking.

Despite promising results, however, this review also highlights considerable gaps in existing research that need to be addressed, which include insufficient studies at lower elementary grades, lack of longitudinal studies, methodological limitations that limit causal inferences, insufficient consideration of equity dimensions, and limited knowledge of scalability and sustainability beyond researcher-managed conditions. Therefore, it is recommended that future studies should seek to address these gaps by conducting rigorous experimental designs with diverse populations, longitudinal studies of long-term effects, examination of implementation at scale in natural settings, and consideration of equity dimensions in terms of how integration affects different backgrounds and different learners. For educational practice, it is recommended to invest in technology infrastructure, high-quality integrated curriculum materials, teacher professional development, allocation of instructional time, and assessment of all aspects of student learning developed by RME-GeoGebra integration.

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