REVIEW PAPER

# GeoGebra-assisted instructional strategies for developing the students' mathematical communication skills: A systematic review in Indonesian high schools

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**Abstract**

This systematic review aims to identify, categorize, and evaluate the effectiveness of GeoGebra-assisted instructional strategies reported in various published studies in developing mathematical communication skills among Indonesian high school students. Specifically, the review seeks to: (1) identify and categorize the types of GeoGebra-assisted instructional strategies employed by Indonesian teachers; (2) synthesize evidence regarding their effectiveness on students' mathematical communication skills; and (3) analyze implementation challenges and facilitating factors within the Indonesian educational context. Following the PRISMA framework, the study analyzed 20 empirical articles published between 2024 and 2025 which met the preset criteria. The use of Geogebra in the three predominant instructional strategies, such as Problem-Based Learning (PBL), Project-Based Learning (PjBL), and Discovery Learning, could enhance students' visual, symbolic, and verbal communication skills. The synthesis reveals that GeoGebra's interactive features facilitate mathematical representation and discourse, though implementation faces challenges including infrastructure limitations and varying levels of teacher readiness. Facilitating factors include GeoGebra's accessibility, visual capabilities, and compatibility with collaborative learning approaches. The novelty of this review lies in its focused synthesis of implementation dynamics within the Indonesian context. Practical implications underscore the need for targeted professional development and institutional support to optimize GeoGebra integration. This study contributes an evidence-based framework to guide educators and policymakers in fostering effective, communication-oriented mathematics instruction.

**Keywords**: GeoGebra-assisted instruction, instructional strategies, mathematical communication skills

## INTRODUCTION

In the 21st century, mathematical proficiency has evolved beyond computational fluency to encompass higher-order thinking skills such as reasoning, problem-solving, and communication, competencies essential for navigating increasingly complex, data-driven societies (Amland et al., 2024). Global educational frameworks, including the Programme for International Student Assessment (PISA), emphasize mathematical communication as a central component of mathematical literacy, reflecting the ability to articulate, interpret, and evaluate mathematical ideas both verbally and symbolically (Anisa et al., 2023). This communicative dimension of mathematics not only supports cognitive understanding but also enables collaborative inquiry and creative reasoning, aligning with contemporary pedagogical imperatives for holistic learner development.

In this context, the integration of technology-enhanced learning tools, particularly Dynamic Mathematics Software (DMS) such as GeoGebra, has gained prominence for its capacity to foster interactive exploration and visualization of abstract mathematical concepts (Hillmayr et al., 2020). Such technologies enable learners to construct and manipulate mathematical representations dynamically, thus bridging conceptual understanding and expressive ability. Within Indonesia, these global trends resonate strongly with national educational priorities aimed at strengthening STEM education and cultivating human capital to meet the demands of the *Merdeka Belajar* (Freedom to Learn) curriculum reform. The government's focus on digital literacy, pedagogical innovation, and equitable access to quality mathematics education underscores the critical importance of exploring GeoGebra-assisted instructional strategies as a means to enhance mathematical communication skills among Indonesian high school students (Pinto et al., 2025).

Despite Indonesia's ongoing educational reforms, the development of mathematical communication skills among high school students remains a significant challenge (Lubis et al., 2023). International assessments such as PISA and TIMSS consistently reveal that Indonesian students struggle not only with problem-solving and reasoning but also with expressing mathematical ideas coherently, an indication of underdeveloped communication competence (Manggala & Yuniawatika, 2023). This gap is exacerbated by the persistence of teacher-centered instructional approaches, where emphasis is placed on procedural fluency and rote memorization rather than discussion, explanation, and conceptual understanding (Epih, 2024). Addressing this discrepancy requires innovative tools that can actively engage students in constructing and articulating mathematical meaning.

In this regard, GeoGebra, a freely available and widely accessible DMS, presents a promising solution. Its dynamic, interactive, and visual features allow students to explore mathematical relationships in real time, facilitating dialogue and reflective thinking as they visualize transformations, construct models, and test conjectures. By transforming abstract concepts into manipulable representations, GeoGebra can serve as a catalyst for mathematical communication, enabling learners to externalize their reasoning processes and engage collaboratively in meaning-making, thereby bridging the gap between curriculum aspirations and classroom realities in Indonesian mathematics education (Seftiana et al., 2024).

While GeoGebra offers substantial potential for enhancing students' mathematical communication, its effectiveness is neither automatic nor uniform, but rather contingent upon the pedagogical design and implementation that accompany its use. The relationship between the tool, the teaching method, and the learning outcome is inherently complex and dynamic, shaped by multiple interdependent factors within the learning environment (Juandi et al., 2021). GeoGebra itself does not inherently produce communicative competence; rather, it functions as a mediational tool whose impact depends on how teachers orchestrate learning experiences, how they design tasks, facilitate discourse, and structure opportunities for collaborative reasoning (Baye et al., 2021). Thus, the development of mathematical communication emerges from the synergistic interaction among the technological affordances of GeoGebra, the pedagogical intentions of the teacher, the cognitive engagement of the learner, and the socio-discursive context of the classroom.

The complexity of the interaction between technology, pedagogy, and learning outcomes is particularly salient within the Indonesian educational context, where systemic and contextual challenges often constrain the effective integration of tools like GeoGebra (Firmansyah, 2025). Compounding these challenges is the fragmented nature of existing research, which tends to consist of small-scale, context-specific studies with inconsistent findings and a lack of comprehensive synthesis focusing specifically on communication-oriented outcomes (Raisatunnisa et al., 2025). These converging factors underscore the need for a systematic review that examines how GeoGebra-assisted instructional strategies can be designed and

contextualized to overcome these barriers, thereby clarity the nuanced dynamics that influence their effectiveness in Indonesian classrooms.

The integration of technology in mathematics education is pivotal for developing 21st-century skills, with mathematical communication being a core component for student success. In Indonesia, GeoGebra has emerged as a prominent dynamic mathematics software to enhance learning hence a comprehensive synthesis that consolidates the specific instructional strategies employed is crucial to discern evidence-based best practices, identify gaps in the current research landscape, and provide coherent guidance for educators and policymakers. Therefore, a systematic consolidation of existing evidence is necessary to map the pedagogical approaches, evaluate their outcomes, and inform future educational practices and research. The objectives of this systematic literature review are:
 (1) to identify and categorize the types of GeoGebra-assisted instructional strategies that Indonesian high school mathematics teachers employ to develop students' mathematical communication skills,
 (2) to synthesize the reported evidence regarding the effectiveness of GeoGebra-assisted strategies on specific aspects of students' mathematical communication skills, and
 (3) to analyze the challenges and facilitating factors encountered by teachers in the implementation of GeoGebra-assisted instructional strategies within the Indonesian educational context.

## RESEARCH METHOD

This study employed a Systematic Literature Review (SLR) methodology guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework (Page et al., 2021). The systematic approach was chosen to comprehensively identify, evaluate, and synthesize all relevant research concerning teaching strategies for developing mathematical communication skills by the use of GeoGebra among high school students.

### Article search strategy

A systematic electronic search was performed to identify relevant literature published within the recent two-year period (2024–2025). The primary database queried was Google Scholar, due to its extensive coverage of both international and Indonesian national journals. To capture the breadth of relevant studies, a comprehensive search string was constructed using Boolean operators. The key terms were combined as follows:

*("GeoGebra" OR "dynamic mathematics software") AND ("mathematical communication" OR "komunikasi matematis") AND ("high school" OR "SMA" OR "Sekolah Menengah Atas") AND ("Indonesia")*

The search was limited to the title, abstract, and keywords of publications. No language restrictions were applied at the search stage to maximize retrieval, though the final selection criteria included language specifications. The initial search results were exported and managed using the Mendeley reference manager to facilitate the efficient handling of citations and the removal of duplicate entries.

### Article selection criteria

The identified records were screened against predefined inclusion and exclusion criteria to determine their eligibility for the final synthesis. These criteria were established to ensure the selected studies were directly pertinent to the review's objectives. The specific criteria are delineated in Table 1.

**Table 1.** Inclusion and exclusion criteria

| Criterion | Inclusion | Exclusion |
|---|---|---|
| Publication Period | 2024 – 2025 | Published before 2024 |
| Population & Context | Indonesian high school (SMA/MA) students and/or teachers | Other educational levels (e.g., junior high, university) or non-Indonesian contexts |
| Intervention | Studies that empirically investigate an instructional strategy (e.g., PBL, Discovery Learning) assisted by GeoGebra and its effect on mathematical communication skills. For studies employing a comparative design (e.g., experiments, quasi-experiments), a non-GeoGebra control or comparison group is required for inclusion to allow for a direct assessment of the software's effectiveness. | Studies where GeoGebra is mentioned only peripherally and not as a core component of the instructional intervention. Studies without a measurable outcome for mathematical communication skills. |
| Outcome | Investigates or reports on aspects of mathematical communication skills (e.g., written, oral, representational) | Focuses solely on other outcomes (e.g., conceptual understanding without communication, general motivation) |
| Study Type | Empirical research (qualitative, quantitative, or mixed-methods); peer-reviewed journal articles or conference proceedings | Systematic reviews, opinion pieces, editorials, theses, dissertations, or non-empirical articles |
| Language | Indonesian or English | Languages other than Indonesian or English |
| Full Text Availability | Full text is accessible and retrievable | Full text is unavailable |

### Article selection process

The selection of final articles for analysis adhered to the structured process outlined by the PRISMA flow diagram, as illustrated in Figure 1. The process involved four distinct phases, such as identification from the database, identification (uneligible removal), screening, and inclusion.

### Data collection and analysis

Based on the data presented in Appendix 1, data extraction from 20 journal articles, the analysis reveals a concentrated focus on a specific set of instructional models combined with GeoGebra to enhance mathematical communication skills. Data were systematically extracted into a standardized matrix, capturing key elements such as the research topic, the specific GeoGebra-assisted instructional strategy employed, and the reported findings related to mathematical communication. The synthesis of these 20 articles indicates that the primary pedagogical approaches investigated are Problem-Based Learning (PBL), Discovery Learning, Cooperative Learning (notably Think-Pair-Share and Student Facilitator and Explaining), and Project-Based Learning (PjBL). These models are consistently integrated with GeoGebra's dynamic visualization and interactive capabilities to serve as a catalyst for improving students' ability to represent mathematical ideas, articulate reasoning, and engage in collaborative mathematical discourse.

## RESULTS AND DISCUSSION

### Typology of GeoGebra-assisted instructional strategies in Indonesia

Based on the analysis of recent studies in Indonesia, GeoGebra is integrated into a diverse range of instructional strategies, with several dominant typologies emerging. The most frequently employed strategies are PBL (Amallya et al., 2025; Hadi et al., 2024; Nono et al., 2025; Rohmana

et al., 2025; Sinaga et al., 2025), Project-Based Learning (Hasibuan & Yahfizam, 2024; Salama et al., 2025; Rohmana et al., 2025), and Discovery Learning (Danny et al., 2024; Sofwatun et al., 2025; Linda et al., 2024).
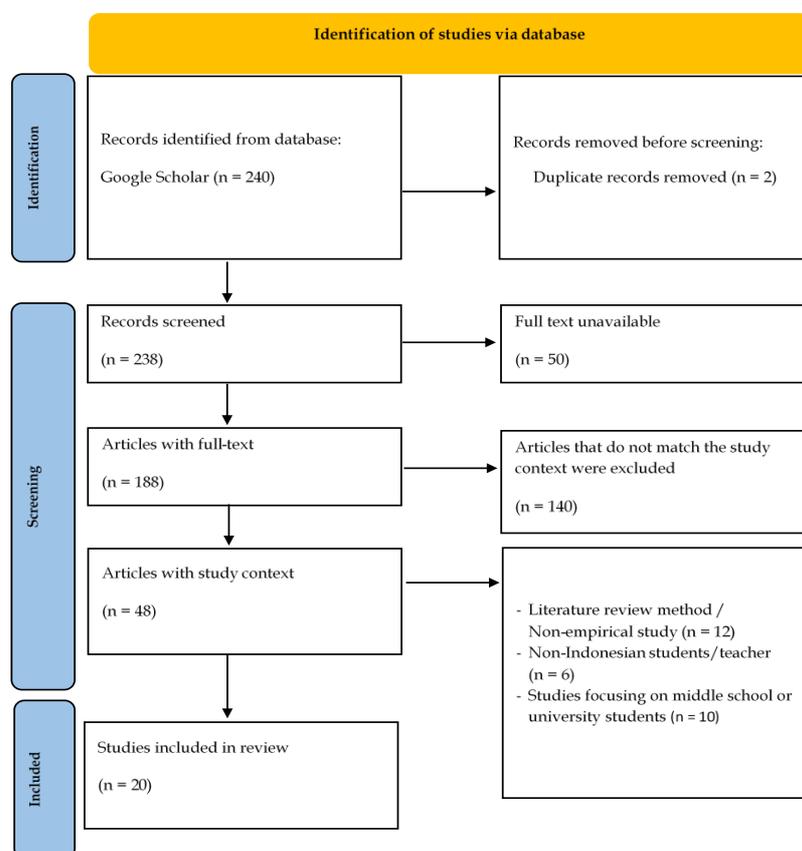


**Figure 1.** PRISMA flow diagram of the article selection.

In these models, GeoGebra primarily functions as a dynamic visualization and exploration tool that helps students discover mathematical relationships, model problems, and verify their solutions, thereby actively engaging them in the learning process. The detailed as presented in the Table 2.

Beyond these core models, other effective typologies include Cooperative Learning (Halim et al., 2024), often structured with techniques like Think-Pair-Share, and more direct, interactive approaches such as Hands-On Learning and Direct Instruction (Widyastiti et al., 2024). Furthermore, studies also explore hybrid or specific frameworks, such as the Student Facilitator and Explaining (SFAE) model (Linda et al., 2024), the 6E Instructional Model (Prasetya et al., 2025), and the Reciprocal Teaching model (Hakim et al., 2024).

Across all these typologies, a common thread is GeoGebra's role in enhancing interactivity, collaboration, and, crucially, providing a medium for students to articulate and represent mathematical ideas visually and symbolically, which directly supports the development of mathematical communication skills. The most frequently used GeoGebra-assisted instructional strategies as presented in Figure 2.

**The impact of GeoGebra-assisted strategies on mathematical communication skills**
Based on the synthesis of the provided studies, GeoGebra-assisted learning strategies consistently demonstrate a significant positive impact on enhancing students' mathematical communication skills. This improvement is primarily evidenced through students' enhanced

ability in multiple representational domains. Specifically, students showed marked progress in visual representation, such as creating and interpreting diagrams, graphs, and geometric constructions (Rafidah & Maharani, 2024; Gustin et al., 2024; Sinaga et al., 2025; Sofwatun et al., 2025), and symbolic representation, which involves expressing situations and ideas using mathematical symbols and models (Danny et al., 2024; Gustin et al., 2024; Hadi et al., 2024).

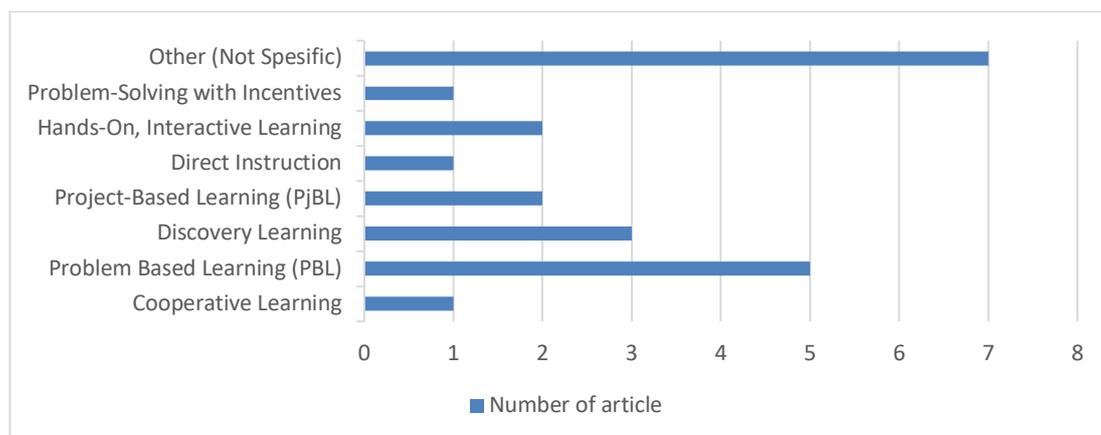**Table 2.** Typology of GeoGebra-Assisted Instructional Strategies

| No. | Author(s) | Typology of GeoGebra-assisted instructional strategies | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | CL[a] | PBL[b] | DL[c] | PjBL[d] | DI[e] | HOIL[f] | PSI[g] | Others |
| 1 | (Halim et al., 2024) | ■ | | | | | | | |
| 2 | (Sinaga et al., 2025) | | ■ | | | | | | |
| 3 | (Danny et al., 2024) | | | | | | | | ■ |
| 4 | (Hasibuan & Yahfizam, 2024) | | | | ■ | | | | |
| 5 | (Amallya et al., 2025) | | ■ | | | | | | |
| 6 | (Widyastiti et al., 2024) | | | | | ■ | | | |
| 7 | (Rafidah & Maharani, 2024) | | | ■ | | | | | |
| 8 | (Gustin et al., 2024) | | | | | | | | ■ |
| 9 | (Salama et al., 2025) | | | | ■ | | | | |
| 10 | (Febrianti & Dasari, 2024) | | | | | | ■ | | |
| 11 | (Hadi et al., 2024) | | ■ | | | | | | |
| 12 | (Linda et al., 2024) | | | ■ | | | | | |
| 13 | (Setyaningrum & JaelanI, 2025) | | | | | | | | ■ |
| 14 | (Sofwatun et al., 2025) | | | ■ | | | | | |
| 15 | (Ramadiana et al., 2024) | | | | | | | | ■ |
| 16 | (Hanifah et al., 2025) | | | | | | | | ■ |
| 17 | (Rohmana et al., 2025) | | ■ | | | | | | |
| 18 | (Nono et al., 2025) | | ■ | | | | | | |
| 19 | (Prasetya et al., 2025) | | | | | | | | ■ |
| 20 | (Hakim et al., 2024) | | | | | | | | ■ |

Note: [a]Cooperative learning, [b]Problem-based learning, [c]Discovery learning, [d]Project-based learning, [e]Direct instruction, [f]Hands-on interactive learning, [g]Problem-solving with incentives

Furthermore, the interactive and collaborative nature of strategies like TPS (Think-Pair-Share) and PBL (Problem-Based Learning) facilitated by GeoGebra fostered more active verbal and written communication, where students gained confidence in explaining their reasoning, presenting work, and engaging in discussions (Hasibuan & Yahfizam, 2024; Amallya et al., 2025; Salama et al., 2025; Linda et al., 2024).

Statistical evidence further corroborates this positive influence. For instance, one study confirmed a statistically significant effect of a GeoGebra-assisted model on mathematical communication skills, albeit with a modest determinant coefficient of 16.0% (Halim et al., 2024). Other studies reported notable increases in post-test scores and high achievement percentages across specific communication indicators, such as explaining ideas using tables and graphs (91.66%) and expressing everyday events in mathematical language (90.62%) (Salama et al., 2025; Febrianti & Dasari, 2024). The integration of GeoGebra not only improved the clarity, accuracy, and flexibility of student communication (Hasibuan & Yahfizam, 2024), but also promoted deeper conceptual understanding and collaborative learning, which are foundational to effective mathematical discourse (Amallya et al., 2025; Hakim et al., 2024). However, it is noteworthy that while the tool significantly supports reasoning and visualization, its technical quality alone may not be the primary driver of learning outcomes, emphasizing the importance

of the pedagogical context in which it is applied (Febrianti & Dasari, 2024; Setyaningrum & Jaelani, 2025).



**Figure 2.** Number of articles using GeoGebra-assisted instructional strategies.

**Implementation dynamics: Challenges and facilitating factors**

The synthesis of 20 recent studies reveals a complex landscape of dynamics influencing the implementation of technology-enhanced learning models, particularly GeoGebra, in mathematics education (See Appendix 2). The pre-intervention context is frequently characterized by significant challenges that hinder effective learning. These include persistent infrastructural and resource limitations, such as unequal student access to hardware and reliable internet (Hasibuan & Yahfizam, 2024; Febrianti & Dasari, 2024; Hanifah et al., 2025), and a prevalent reliance on conventional, teacher-centered instructional methods that lead to student passivity and difficulties in grasping abstract concepts (Widyastiti et al., 2024; Hakim et al., 2024; Nono et al., 2025). Furthermore, a recurrent theme is the limited proficiency and familiarity of both teachers and students with digital tools, requiring additional time for training and adaptation (Sinaga et al., 2025; Rafidah & Maharani, 2024; Gustin et al., 2024; Sofwatun et al., 2025). These foundational challenges set the stage for examining the specific facilitating factors that enable successful intervention.

Despite these hurdles, the studies consistently identify powerful facilitating factors that can effectively counteract the challenges. The most prominent enabler is the intrinsic value of GeoGebra software itself, whose visual and interactive features make abstract mathematical concepts tangible, thereby significantly increasing student engagement, motivation, and understanding (Danny et al., 2024; Widyastiti et al., 2024; Gustin et al., 2024; Ramadiana et al., 2024). This technological advantage is optimally leveraged when coupled with student-centered learning models like Problem-Based Learning (PBL), Project-Based Learning (PjBL), and Think-Pair-Share (TPS), which structure the learning environment to foster active participation, collaboration, and critical thinking (Halim et al., 2024; Amallya et al., 2025; Salama et al., 2025). Thus, the successful implementation of these interventions is contingent on a supportive ecosystem comprising structured teaching materials, consistent and guiding teacher facilitation, and strong institutional backing, including access to adequate technological resources (Hanifah et al., 2025; Linda et al., 2024; Salama et al., 2025). This combination of innovative technology, effective pedagogy, and systemic support creates a dynamic where facilitating factors can directly address and overcome pre-existing implementation challenges.

**Implications for pedagogical practices and recommendations for future research**

Based on the findings of this systematic review, pedagogical practices should prioritize the strategic integration of GeoGebra within student-centered instructional frameworks such as

Problem-Based Learning, Project-Based Learning, and Discovery Learning to maximize the development of mathematical communication skills. The dynamic visualization and exploration capabilities of the software are most effective when embedded in lessons that explicitly require students to articulate reasoning, represent ideas visually and symbolically, and collaborate in discussions. To overcome implementation challenges, educators require professional development focused on both technological proficiency and the facilitation of discourse-rich, inquiry-based learning environments, supported by adequate institutional infrastructure and structured teaching materials. For future research, longitudinal studies are needed to investigate the sustained impact of these strategies on communication skills beyond immediate post-intervention gains. Further inquiry should also explore the specific mechanisms by which different GeoGebra-assisted typologies foster various facets of communication, and examine the contextual factors that influence scalability and effectiveness across diverse Indonesian educational settings to develop more nuanced, localized implementation models.

## CONCLUSION

Based on the synthesis of recent studies, this review concludes that integrating GeoGebra within student-centered instructional models, such as Problem-Based Learning (PBL), Project-Based Learning (PJBL), and Discovery Learning, effectively enhances Indonesian high school students' mathematical communication skills. The key finding is that GeoGebra acts as a dynamic visualization and exploration tool, significantly improving students' abilities in visual, symbolic, and verbal/written communication by making abstract concepts tangible and fostering collaborative discourse. A crucial practical implication is that for successful implementation, pedagogical practices must move beyond the tool's technical use. Educators should embed GeoGebra within structured, inquiry-based activities that explicitly require students to explain their reasoning, while also receiving institutional support through professional development and improved technological infrastructure to overcome prevalent challenges. For future research, it is recommended to conduct longitudinal studies to assess the long-term retention of communication skills and to further investigate the specific contextual factors within diverse Indonesian schools that influence the success and scalability of these GeoGebra-assisted strategies.

## DECLARATION

**Author contribution**
All authors contribute in the research and/or writing the paper, and approved the final manuscript.

| | |
|---|---|
| *Mutiara M. Ilyas* | Conceptualizing the research idea, leading the investigation, setting up the methodology, collecting data, analyzing data, and writing the first draft. |
| *Irwan Akib* | Conceptualizing the research idea, reviewing the validity of the methodology, supervising the data collection, assisting the investigation, enriching the data analysis. |
| *Muhammad Muzaini* | Conceptualizing the research idea, reviewing the validity of the methodology, supervising the data collection, assisting the investigation, enriching the data analysis. |

**Conflict of interest**
All authors declare that they have no competing interests.

**Ethics declaration**
We as authors acknowledge that this work has been written based on ethical research that conforms with the regulations of our institutions and that we have obtained the permission from the relevant institutes when collecting data. We support the International Journal on Education Insight (IJEI) in maintaining the high standards of personal conduct, practicing honesty in all our professional practices and endeavors.

**The use of artificial intelligence**
We do not use any generative AI tools to write any part of this paper.

**Additional information**
Not available.

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## APPENDIX

**Appendix 1**
Data Extraction from 20 Journal Articles

| No. | Research Topic and Author | Specific Geogebra-assisted Instructional Strategies | Key Findings Related to the Effectiveness on Mathematical Communication Skills |
|---|---|---|---|
| 1 | Pengaruh Model Pembelajaran Cooperative Learning Dengan Bantuan Aplikasi Geogebra Terhadap Kemampuan Komunikasi Matematis Siswa Pada Materi Program Linear Di SMA Kristen Kalam Kudus Pematangsiantar (Halim et al., 2024) | The specific instructional strategy used was the Cooperative Learning model with the Think-Pair-Share (TPS) type, assisted by the Geogebra application.<br>Model & Type: Cooperative Learning Think-Pair-Share (TPS). This model involves students first thinking individually (Think), then discussing in pairs (Pair), and finally sharing their ideas with the larger group or class (Share). | The study found a positive and significant influence of the Geogebra-assisted TPS model on students' mathematical communication skills.<br>- Statistical Evidence: Independent variable (the instructional model) had a significant effect on the dependent variable (mathematical communication skills).<br>- Effect Size: The study notes this indicates a "very weak" relationship according to its interpretation table, but it is statistically significant. |
| 2 | Pengaruh Penerapan Media Geogebra Dalam Model Pembelajaran Problem Based Learning Terhadap Kemampuan Komunikasi Matematis Siswa Sma Negeri 8 Medan Kelas XI Pada Materi Persamaan Lingkaran (Sinaga et al., 2025) | The instructional strategy combined the Problem Based Learning (PBL) model with GeoGebra as an interactive learning medium. | The article indicates that the students' mathematical communication was measured through their ability to:<br>- Explain the steps and processes they undertook during problem-solving.<br>- Present their group's work and findings clearly in front of the class.<br>- Engage in discussion and provide feedback, which deepened their conceptual understanding and communication skills.<br>- Use GeoGebra to visualize and represent mathematical concepts (like plotting points and circles), which aided in clarifying and communicating their ideas. |
| 3 | The Implementation of Geogebra-Assisted Discovery Learning Approach Towards Mathematical Communication Ability of Vocational Students (Danny et al., 2024) | The specific instructional strategy was the integration of the Discovery Learning model assisted by GeoGebra software. | The study measured mathematical communication skills using three indicators:<br>- MBN: Communicating mathematical ideas using real objects, pictures, or diagrams.<br>- MIS: Using objects, graphs, or algebra to explain ideas and relationships orally or in writing.<br>- MPS: Using mathematical symbols to express everyday situations. |
| 4 | Pembelajaran Berbasis Proyek Menggunakan Software Matematika Geogebra Terhadap | The primary instructional strategy discussed is Project-Based Learning (PjBL/Pembelajaran Berbasis Proyek). The specific strategy | The research concludes that using Geogebra has a positive effect on students' mathematical communication skills. The specific |

| No. | Research Topic and Author | Specific Geogebra-assisted Instructional Strategies | Key Findings Related to the Effectiveness on Mathematical Communication Skills |
|---|---|---|---|
|  | Kemampuan Komputasi Siswa (Hasibuan & Yahfizam, 2024) | involves using Geogebra as a tool within this model to help students solve problems and complete projects. | aspects that showed improvement are:<br>- Accuracy, Speed, Flexibility, and Clarity: Students demonstrated more accurate, faster, more flexible, and clearer communication skills in the process of creating geometric drawings.<br>- Active Communication and Idea Conveyance: Students became more active in communicating with their peers in their groups when conveying mathematical ideas.<br>- Confidence in Explanation: Students were braver in explaining the results of their discussions and did not hesitate to express their opinions or respond to their friends' opinions. |
| 5 | Problem based learning with geogebra: Impact on mathematical communication skills and mathematical problem solving (Amallya et al., 2025) | The study used the Problem Based Learning (PBL) model assisted by GeoGebra | The study found that GeoGebra-assisted PBL significantly improved students' mathematical communication skills. Specific aspects included:<br>- Ability to express mathematical ideas both verbally and in writing.<br>- Improved accuracy in identifying, planning, and implementing solution steps.<br>- Better interpretation of problems into mathematical forms.<br>- Increased ability to use mathematical symbols, diagrams, and language effectively. |
| 6 | Utilization of Geogebra Application as Learning Media in Learning The Three-Dimensional to Increase Students' Interest in Learning (Widyastiti et al., 2024) | - Direct Instruction and Demonstration: The teaching team introduced the GeoGebra application, its use, its features, and its menus to the students.<br>- Hands-On, Interactive Learning: After the teacher's explanation, students immediately practiced using GeoGebra on their own devices.<br>- Problem-Solving with Incentives: In the final stage, students were given three test questions on the three-dimensional distance concepts. To increase motivation, a reward was given to students who successfully answered the questions correctly. | The key findings of this specific research are concentrated on student interest, learning outcomes, and the perceived benefits of using GeoGebra. While one of the perceived benefits measured was "The use of GeoGebra learning media encourages me to think critically," which is a related skill, mathematical communication (e.g., explaining, justifying, representing ideas) was not a measured variable in the results section. |
| 7 | Penggunaan Aplikasi Geogebra Sebagai Media | - Exploration and Discovery Learning: Students explore and | - GeoGebra improved students' ability to represent mathematical |

| No. | Research Topic and Author | Specific Geogebra-assisted Instructional Strategies | Key Findings Related to the Effectiveness on Mathematical Communication Skills |
|---|---|---|---|
| | Kreatifitas Siswa SMA (Rafidah & Maharani, 2024) | find mathematical relationships through dynamic manipulation of shapes and functions.<br>- Construction-Based Learning: Learners use GeoGebra tools (File, Edit, View, Tools, etc.) to construct graphs, coordinate points, and geometric objects.<br>- Communication and Representation Tools: GeoGebra functions as a medium for representing mathematical ideas visually and symbolically, supporting problem solving and mathematical discussions | ideas using symbols, diagrams, and graphs.<br>- It enhanced clarity in expressing solutions for Cartesian coordinate problems and supported students' understanding of geometric transformations.<br>- The study found notable improvement in post-test results, a positive effect on comprehension, visualization, and communication performance.<br>- Students became more active, motivated, and able to convey their reasoning through interactive, visual exploration |
| 8 | Penggunaan Media Software Geogebra Untuk Meningkatkan Kemampuan Representasi Matematis Siswa SMA (Gustin et al., 2024) | The activities emphasized interactive and visual exploration, allowing students to manipulate figures, observe changes dynamically, and interpret the underlying mathematical relationships. | Students in the GeoGebra group demonstrated stronger abilities in:<br>- Visual representation: creating and interpreting diagrams, tables, and graphs.<br>- Symbolic representation: formulating equations or mathematical expressions.<br>- Verbal representation: articulating reasoning in written form. |
| 9 | The Effect of Project-Based Learning on Students' Mathematical Communication Skills (Salama et al., 2025) | The Project-Based Learning (PjBL) model was implemented through project activities involving GeoGebra software. | The study concluded that GeoGebra-based PjBL fosters active learning, collaboration, and contextual understanding, leading to better verbal and written mathematical expression. Improvement was found across four indicators of mathematical communication:<br>- Creating mathematical situations in written form (74.65%)<br>- Explaining mathematical ideas in writing, using tables and graphs (91.66%)<br>- Connecting images/graphs to mathematical ideas (83.33%)<br>- Expressing everyday events in mathematical symbols, language, or models (90.62%) |
| 10 | Creativity Increment and GeoGebra Classroom Quality: Impact on Student Learning (Febrianti & Dasari, 2024) | The study implemented interactive learning through GeoGebra Classroom, focusing on quadratic function materials. The instructional strategy involved:<br>- Developing validated GeoGebra-based learning activities to facilitate exploration and concept discovery. | While the study primarily measured creativity, it implicitly supports components of mathematical communication through:<br>- Encouraging students to express and elaborate mathematical ideas visually (e.g., graphing and problem-solving with GeoGebra). |

| No. | Research Topic and Author | Specific Geogebra-assisted Instructional Strategies | Key Findings Related to the Effectiveness on Mathematical Communication Skills |
|---|---|---|---|
| | | - Integrating interactive visualizations that allowed students to manipulate graphs and parameters dynamically.<br>- Using pre- and post-creativity tests and feedback questionnaires to assess engagement.<br>- Applying GeoGebra Classroom as a collaborative digital space, where teachers monitored student responses and progress in real-time without requiring software installation. | - Promoting interaction and reflection as students engaged with digital tasks collaboratively.<br>- Results showed a significant increase in students' creativity ($p < 0.05$), which correlates with improved comprehension and expression in mathematics, particularly in problem interpretation and idea fluency, both integral to mathematical communication. However, the quality of GeoGebra Classroom media did not significantly affect learning outcomes, suggesting that while creativity (and by extension communication) improved, the media's technical quality alone was not a determining factor in achievement. |
| 11 | Improving Mathematical Communication Skills Through the Geogebra-helped PBL and Direct Instruction Reviewed from the Level of Learning Independence (Hadi et al., 2024) | Problem-Based Learning (PBL) model as the instructional approach used to enhance mathematical communication | The study confirmed that both GeoGebra-assisted instructional methods significantly enhanced students' mathematical communication skills. Although the PBL model led to high improvement scores, no significant overall difference in effectiveness was found between the PBL and Direct Instruction groups. However, a key interaction effect emerged: students with high learning independence benefited most from the GeoGebra-assisted PBL approach, indicating that the combined influence of the instructional model and a student's independence level plays a crucial role in improving these skills. |
| 12 | Analysis HOTS Problem Solving: Student Learning Outcomes from Student Facilitator and Explaining and Geogebra-Assisted Discovery Learning Models (Linda et al., 2024) | - Student Facilitator and Explaining (SFAE): A cooperative learning model that encourages students to actively present ideas, exchange explanations, and clarify concepts with peers using GeoGebra to visualize abstract mathematical problems.<br>- Discovery Learning Model: A problem-based strategy where students discover mathematical principles through experimentation, data collection, and analysis supported by GeoGebra for visualization and computation of linear program material | - The SFAE model integrated with GeoGebra yielded higher post-test results (mean = 52.947) than the GeoGebra-assisted Discovery Learning model (mean = 20.000), indicating stronger student learning outcomes and cognitive engagement.<br>- GeoGebra enhanced students' reasoning, problem-solving, and critical thinking, which are core components of mathematical communication skills, such as the ability to express reasoning processes, connect mathematical representations, and apply |

| No. | Research Topic and Author | Specific Geogebra-assisted Instructional Strategies | Key Findings Related to the Effectiveness on Mathematical Communication Skills |
|---|---|---|---|
| | | | abstract concepts to real-life contexts.<br>- The technology-supported SFAE model improved students' activeness and interaction, allowing them to articulate ideas more clearly, thus fostering better mathematical discourse and understanding |
| 13 | Learning Videos and Geogebra: Do They Really Help Students Solve Their Answers? (Setyaningrum & JaelanI, 2025) | The study implemented Geogebra-based tasks focused on Systems of Linear Equations in Two Variables (SPLDV), integrating:<br>- Manual problem-solving (graphical method) followed by validation using the Geogebra application.<br>- Dual-phase activity: students first solved problems manually, then checked and visualized their answers using Geogebra.<br>- Geogebra functioned as a verification tool rather than a primary teaching method, encouraging students to compare and analyze discrepancies between manual and digital solutions. | Learning videos did not effectively enhance students' mathematical understanding or communication; students often needed re-explanation and could not recall steps independently. Geogebra, however, supported students' reasoning and accuracy by helping them visualize and confirm solutions, although excessive reliance risked reducing their manual problem-solving initiative. |
| 14 | Effectiveness of Discovery Learning Assisted by GeoGebra in Enhancing Students' Mathematical Literacy (Sofwatun et al., 2025) | The study implemented a Discovery Learning model with GeoGebra integrated as a key tool | - Translating problems into mathematical models: Students improved in representing real-world problems using variables, diagrams, and graphs via GeoGebra.<br>- Interpreting results in context: Students were able to connect mathematical solutions back to real-life situations, though some struggled with reinterpretation without reminders.<br>- Collaborative communication: Group discussions and presentations facilitated the exchange of mathematical ideas and reasoning.<br>- Use of symbolic and visual representations: GeoGebra helped students bridge iconic (visual) and symbolic (algebraic) representations, supporting clearer communication of mathematical concepts. |
| 15 | Improving students' problem-solving abilities by using geogebra learning media on three-dimensional | - The learning process involved students using Student Worksheets (LKPD) alongside GeoGebra. | While the article's primary focus is on problem-solving ability, it touches upon aspects related to mathematical communication. |

| No. | Research Topic and Author | Specific Geogebra-assisted Instructional Strategies | Key Findings Related to the Effectiveness on Mathematical Communication Skills |
|---|---|---|---|
| | material (Ramadiana et al., 2024) | - The teacher provided more explanation on solving mathematical problems according to problem-solving steps in the second cycle to correct previous deficiencies. | |
| 16 | Uji Coba E-LKPD Garis Singgung Persekutuan Luar pada Siswa dan Guru SMA IT Iqra' Kota Bengkulu (Hanifah et al., 2025) | The primary instructional strategy was the implementation of an Electronic Student Worksheet (E-LKPD) based on the APOS model (Action, Process, Object, Schema) assisted by GeoGebra. | The activity where students presented their work demonstrated that they were not only able to follow procedural steps but also possessed the ability to re-communicate the concepts and processes they had learned. This indicates an improvement in conceptual thinking skills, visual representation abilities, and mathematical communication skills, as students could coherently explain how to construct circles, draw common external tangents, and calculate the tangent length using GeoGebra. |
| 17 | Efektivitas Model Problem Based Learning dan Project Based Learning Berbantuan GeoGebra Terhadap Kemampuan Pemecahan Masalah (Rohmana et al., 2025) | GeoGebra was used as an aid (*berbantuan* GeoGebra) within both the PBL and PJBL models for teaching the "Sistem Pertidaksamaan Linier Dua Variabel" (Two-Variable Linear Inequality System) material. | The problem-solving indicators used are based on Polya's steps: (1) understanding the problem, (2) devising a plan, (3) carrying out the plan, and (4) looking back. There are no specific findings or discussions regarding students' mathematical communication skills in this study. |
| 18 | Implementasi Model Pembelajaran Problem based Learning Berbantuan Media Audiovisual untuk Meningkatkan Kemampuan Komunikasi Siswa Kelas X SMAN 4 Kupang (Nono et al., 2025) | The instructional strategy was a Problem-Based Learning (PBL) approach assisted by Geogebra. | While the article assesses "communication skills" in a general educational context, it mentions that the initial problem included students' difficulties in mathematical communication, such as:<br>- Inability to convey mathematical concepts using symbols and written notation.<br>- Inability to make effective class presentations on mathematical topics. |
| 19 | Visualizing geometry: exploring the role of geogebra-assisted 6E-IM model in enhancing students' spatial abilities (Prasetya et al., 2025) | The instructional strategies were embedded within the 6E Instructional Model (6E-IM) | - Explanation and articulation during the Explain phase, where students verbalized their understanding of geometric concepts.<br>- Use of visual representations (e.g., nets, 3D models) to communicate spatial relationships.<br>- Structured tasks in worksheets (LKPD) that guided students to analyze and solve problems using spatial reasoning. |

| No. | Research Topic and Author | Specific Geogebra-assisted Instructional Strategies | Key Findings Related to the Effectiveness on Mathematical Communication Skills |
|---|---|---|---|
| 20 | Needs Analysis of Learning Devices With Reciprocal Teaching Model Assisted by Geogebra on Geometric Transformation Material (Hakim et al., 2024) | The study proposes the use of GeoGebra as a dynamic mathematics software to support the Reciprocal Teaching model. | - Improve students' mathematical reasoning skills.<br>- Enhance the effectiveness of students' mathematical communication skills.<br>- Encourage students to communicate their ideas to peers, fostering positive interactions and collaborative learning. |

**Appendix 2**

The Impact of GeoGebra-assisted Strategies on Mathematical Communication Skills

| No. | Author | Reported Challenges (Pre-Intervention Context) | Facilitating Factors (for the Intervention) |
|---|---|---|---|
| 1 | Halim et al. (2024) | Student Difficulties: Students had low mathematical communication skills due to:<br>- Difficulty understanding problems and converting them into mathematical models.<br>- Lack of understanding in reading graphs and representing equations graphically.<br>- Inability to determine the intersection points needed to draw linear graphs. | - Model Advantages: The TPS model was chosen for its benefits, including providing opportunities for students to think, answer, and help each other; increasing student activeness; and fostering peer-to-peer learning and cooperation. |
| 2 | Sinaga et al. (2025) | There is a need for training for mathematics teachers in using GeoGebra and implementing the Problem Based Learning model effectively. This suggests that a lack of teacher proficiency could be a potential challenge. | School Context: The school (SMA Negeri 8 Medan) had already implemented the "Kurikulum Merdeka" (Independent Curriculum), which encourages innovation and freedom for teachers and students, providing a supportive environment for such interventions. |
| 3 | Danny et al. (2024) | - The study did not explicitly detail implementation challenges, but it highlighted that conventional teaching methods still dominate, leading to student boredom and difficulty in understanding abstract concepts.<br>- It implied that teacher creativity and instructional variety are critical for success, suggesting that a lack thereof may be a barrier. | - GeoGebra made learning more engaging and interactive, increasing student motivation.<br>- The software's accessibility via smartphones and the internet made it easy to integrate into lessons.<br>- Discovery Learning encouraged active student involvement, curiosity, and peer collaboration. |
| 4 | Hasibuan and Yahfizam (2024) | - Lack of Hardware Access: Not all students have access to a computer or laptop at home, which limits the effectiveness of using Geogebra outside of school and creates inequality.<br>- Potential for Digital Divide: Issues such as low digital literacy, the inability to focus on screens for long periods, and lack of access to high-speed internet were noted as potential problems for software-based learning in general. | - Positive Learning Outcomes: The software shows positive results on students' computational knowledge, problem-solving abilities, and engagement, making a strong case for its continued use.<br>- User-Friendly Interface: The software's display is considered attractive and easy to understand for both students and teachers.<br>- Alignment with Digital Era: Students today are more comfortable using electronic devices than printed books, making software like Geogebra more effective and engaging for them. |
| 5 | Amallya et al. (2025) | - Students had difficulty interpreting problems into mathematical forms.<br>- Lack of accuracy in identifying and planning solutions.<br>- Students were not accustomed to re-checking their answers.<br>- Initial low mathematical communication and problem-solving skills among students. | - Use of GeoGebra helped make abstract concepts more tangible and visual.<br>- Structured PBL steps encouraged active participation and collaboration.<br>- Small group discussions fostered peer learning and confidence.<br>- Teacher guidance in clarifying and evaluating solutions was crucial. |
| 6 | Widyastiti et al. (2024) | - Initial Low Understanding and Performance: Before the intervention (Cycle 1), students had difficulty, with only 42.37% able to solve problems correctly | - Visualization and Concrete Representation: GeoGebra successfully transformed abstract three-dimensional concepts into clear visual |

GeoGebra-assisted instructional strategies for developing the students' mathematical communication
*M. M. Ilyas, I. Akib, & M. Muzaini*

| No. | Author | Reported Challenges (Pre-Intervention Context) | Facilitating Factors (for the Intervention) |
|---|---|---|---|
| | | on average. A specific challenge noted was student errors in "determining the perpendicular line" when solving point-to-line and point-to-plane distance problems.<br>- Teacher-Centered Conventional Learning: The introduction identifies the conventional, teacher-centered learning model as a root cause of student boredom and lack of understanding, which the study aimed to address. | experiences, making the material "more interesting and easier to understand."<br>- Increased Student Engagement: The hands-on, interactive nature of using the software increased student interest and motivation, as shown by the significant rise in "agree" and "strongly agree" responses in the post-intervention questionnaire.<br>- Ease of Use and Positive Perception: The questionnaire on benefits showed that students found GeoGebra easy to use (80.8% agreement) and that it encouraged independent learning, critical thinking, and creativity, all of which facilitated its successful implementation. |
| 7 | Rafidah and Maharani (2024) | - Many teachers still rely on conventional methods and lack familiarity with digital media.<br>- Limited teacher understanding of students' learning styles and technological integration<br>- Insufficient technological resources and training for effective classroom use | - The simplicity and interactivity of GeoGebra make it accessible for students.<br>- It promotes creativity, engagement, and independent learning.<br>- Visual and real-time feedback features make abstract mathematical concepts more concrete and easier to communicate |
| 8 | Gustin et al. (2024) | - The need for technological readiness (computers and familiarity with GeoGebra).<br>- Students initially requiring guidance to operate the software effectively.<br>- Time constraints in integrating GeoGebra use within standard lesson duration. | - GeoGebra's visual and interactive interface helped students grasp abstract concepts more concretely.<br>- Increased student engagement and curiosity through computer-based, hands-on learning.<br>- Simplified teachers' explanation of problem-solving steps, as results were shown dynamically. |
| 9 | Salama et al. (2025) | - Time-consuming process: PjBL requires extended planning and execution time.<br>- Resource demands: Effective implementation depends on sufficient materials, access to GeoGebra, and technological readiness.<br>- Student participation: Some students were initially passive and required adaptation to the student-centered approach. | - High student engagement: Group projects and GeoGebra visualization increased interest and participation.<br>- Strong teacher facilitation: Teachers' consistent guidance maintained focus and helped overcome learning obstacles.<br>- Collaborative learning climate: Group discussions and presentations enhanced communication and peer learning. |
| 10 | Febrianti and Dasari (2024) | - Limited student access to computers or laptops.<br>- Unequal technological readiness among schools (some lacked computer labs).<br>- Online learning during COVID-19 restricted real-time teacher monitoring.<br>- Certain materials (e.g., problem-based quadratic tasks) were not fully integrated into GeoGebra activities, limiting transfer to test results. | - GeoGebra Classroom's interactive and visual nature effectively increased engagement and creativity.<br>- The ease of online access (via geogebra.org) allowed use without installation barriers.<br>- Validation by experts confirmed high media validity and practicality (scores >0.87, "very good"). |

| No. | Author | Reported Challenges (Pre-Intervention Context) | Facilitating Factors (for the Intervention) |
|---|---|---|---|
| 11 | Hadi et al. (2024) | - Limited teacher supervision during testing led to possible non-independent student answers.<br>- Variation in students' initial abilities required additional support during problem-solving discussions. | - PBL encouraged active engagement, collaboration, and critical reflection.<br>- Real-world contextual problems increased motivation and curiosity. |
| 12 | Linda et al. (2024) | - Limited school facilities hindered the optimal use of GeoGebra in some learning environments.<br>- Variations in class size, gender distribution, and classroom atmosphere affected the results.<br>- Some teachers had not yet maximized the integration of technology-based learning models, limiting the consistency of implementation. | - GeoGebra's interactive, visual features helped bridge abstract mathematical ideas with concrete understanding.<br>- Supportive collaboration between teachers and students increased motivation and engagement.<br>- Institutional support and access to adequate technological tools were identified as key enablers for successful implementation |
| 13 | Setyaningrum and Jaelani (2025) | - Students tended to become dependent on the application, neglecting manual calculation skills.<br>- Errors occurred due to automatic simplification or scale changes in Geogebra when inputting large numbers.<br>- Learning videos were insufficient for conceptual comprehension without teacher mediation. | - Geogebra provided visual reinforcement and immediate feedback, helping students identify and correct errors.<br>- The combination of manual and digital problem-solving created a constructive learning cycle, enhancing understanding and self-evaluation. |
| 14 | Sofwatun et al. (2025) | - Some students had limited prior experience with GeoGebra, requiring additional time to learn the tool.<br>- Limited instructional time constrained the full implementation of the discovery process. | - Structured scaffolding by the researcher helped students overcome technical and conceptual hurdles.<br>- Heterogeneous grouping encouraged peer collaboration and idea exchange.<br>- Use of contextual problems and GeoGebra visualizations made learning more engaging and meaningful. |
| 15 | Ramadiana et al. (2024) | - Initial sub-optimal implementation by the teacher, where not all aspects of teaching activities met the "good" criteria in the first cycle.<br>- Students' initial difficulties in formulating solution steps for mathematical problems, particularly in three-dimensional material, which was exacerbated by online learning during the COVID-19 pandemic.<br>- In the first cycle, the results for teacher activity, student activity, and the problem-solving test had not yet met the success indicator of 75%. | - GeoGebra's Visualization: Its ability to provide a clear visual experience and help students understand abstract geometric concepts and investigate the properties of geometric objects.<br>- Active Learning: GeoGebra enabled students to play an active role in learning, which helped them construct knowledge and understand concepts. |
| 16 | Hanifah et al. (2025) | - Technical Limitations: Insufficient computer devices and some devices being damaged.<br>- Lack of Experience: Both students and some teachers had limited prior experience in operating the GeoGebra software.<br>- Need for Ongoing Support: Participants indicated a need for continued mentoring to habitually integrate GeoGebra into future learning. | - Strong School Support: The school had a well-equipped computer laboratory and a proven track record of supporting innovative learning, evidenced by its high-achieving alumni.<br>- Structured Teaching Materials: The availability of a validated, practical, and effective E-LKPD based on the APOS model provided a clear and systematic guide for both teachers and students. |

| No. | Author | Reported Challenges (Pre-Intervention Context) | Facilitating Factors (for the Intervention) |
|---|---|---|---|
| 17 | Rohmana et al. (2025) | The article does not explicitly list challenges encountered during the implementation of the models or the use of GeoGebra. The discussion focuses on the outcomes of the experimental study. | The primary facilitating factor identified is the use of GeoGebra itself. It is presented as a supportive medium that optimizes the application of PBL and PJBL by providing dynamic visualization and supporting the exploratory nature of these learning models. |
| 18 | Nono et al. (2025) | - Low Student Engagement: One-way communication was dominant during learning.<br>- Lack of Student Participation: Most students rarely asked or answered questions.<br>- Low Self-Confidence: Students lacked the confidence to communicate.<br>- Dense Material Delivery: The presentation of material was too content-heavy.<br>- Use of Uninteresting Media and Conventional Methods: The previous teaching methods and media failed to engage students. | - Use of Audiovisual Media: This made the learning process more attractive, helped students understand the material more easily, and increased their attention and engagement.<br>- Effectiveness of the PBL Model: The PBL approach encouraged students to be proactive, work cooperatively in small groups, collaborate on ideas, and solve problems, which directly fostered communication. |
| 19 | Prasetya et al. (2025) | - Some students' mobile devices did not support QR code scanning, limiting access to GeoGebra resources.<br>- Students initially struggled with transforming 3D shapes into 2D nets and identifying geometric elements.<br>- The study was limited to prism geometry and a specific grade level, which may affect generalizability. | - High validation scores (84%–100%) for all learning tools (modules, worksheets, tests, etc.).<br>- Teacher ability to manage the 6E-IM model was consistently rated high across all sessions.<br>- GeoGebra's interactive and dynamic features helped make abstract concepts more tangible. |
| 20 | Hakim et al. (2024) | - Teachers have never used the Reciprocal Teaching model in mathematics instruction.<br>- Conventional teaching methods (e.g., lecture-based) dominate, leading to low student engagement and understanding. | - High student interest in ICT-based learning (96.7% support the use of ICT in mathematics).<br>- Availability of mobile devices (smartphones, laptops) that can support GeoGebra use.<br>- Positive teacher and student attitudes toward GeoGebra, most are familiar with it and support its use. |