

A Systematic Literature Review of GeoGebra Implementation in Project-Based Learning

Sidhik Hidayatullah^{1*}, Isti Hidayah²

^{1,2}Universitas Negeri Semarang, Semarang, Indonesia

*hidayatullah12223@gmail.com

Abstract

The objectives of this study are to analyze how GeoGebra has been implemented in Project-Based Learning (PjBL) models within mathematics education, to explore the effectiveness of its integration in improving learning outcomes, and to provide insights for future pedagogical approaches involving dynamic mathematics software. This study employed a Systematic Literature Review (SLR) method following the PRISMA protocol to ensure rigorous and transparent article selection and synthesis. The search process involved filtering 428 articles published between 2020 and 2025 using three major academic databases: Google Scholar, Scopus, Semantic Scholar, and Crossref. A final set of 21 articles was selected for in-depth review and analysis based on relevance to the research questions and inclusion criteria. The findings indicate that integrating GeoGebra into PjBL positively enhances students' conceptual understanding, mathematical reasoning, and engagement. Most studies also highlight the role of GeoGebra in facilitating interactive, student-centered learning environments. This review provides evidence-based recommendations for educators and researchers aiming to optimize the use of GeoGebra in project-based learning contexts. It contributes to the growing body of literature supporting the strategic use of digital tools in mathematics education.

Keywords : GeoGebra, Project-Based Learning (PjBL), Mathematics Education, Implementaion, Learning Models.

Background

In mathematics education, students frequently struggle to grasp abstract concepts due to the dominance of conventional instructional methods. These traditional methods typically emphasize verbal explanation and symbol manipulation without sufficient visual aids. As a result, learners often face cognitive overload, especially in complex topics such as algebra, functions, and geometry (Aisy et al., 2022; Rif'at et al., 2024). The lack of visualization in learning materials hinders students' ability to build meaningful mental representations of mathematical structures, which are crucial for problem-solving and higher-order thinking.

Cognitive learning theories, such as Bruner's theory of representation, emphasize the importance of transitioning through enactive (action-based), iconic (image-based), and symbolic (abstract) stages in learning. Bruner (1966) argued that learners grasp abstract ideas more effectively when they are first presented through concrete or visual experiences. Similarly, the Dual Coding Theory by Paivio (1986) states that the combination of verbal and visual information enhances memory retention and comprehension. These theoretical frameworks underscore the critical role of visualization in mathematics education, serving as a bridge between conceptual understanding and symbolic manipulation.

In response to the need for more interactive and visual learning environments, digital tools have gained popularity in education. One such tool is GeoGebra, a free, open-source dynamic mathematics software that integrates algebra, geometry, calculus, and statistics in a visual interface. GeoGebra allows students to construct and manipulate geometric and algebraic representations interactively, enabling them to explore mathematical relationships dynamically. Empirical research has demonstrated the effectiveness of GeoGebra in improving students' mathematical understanding, engagement, and reasoning skills (Panjaitan, 2024). Its real-time feedback

and visual representation capabilities align closely with constructivist learning principles, which emphasize active exploration, immediate feedback, and personal meaning-making.

On the other hand, Project-Based Learning (PjBL) is a student-centered pedagogical model grounded in constructivist and experiential learning theories. According to Thomas (2000), PjBL engages students in meaningful tasks, collaboration, and sustained inquiry, culminating in a final product that reflects their learning. PjBL is especially effective in developing 21st-century skills such as critical thinking, creativity, and collaboration (Bell, 2010). In mathematics education, PjBL encourages learners to apply mathematical knowledge to solve real-world problems, promoting deeper understanding and contextual relevance (Cruz et al., 2022).

When combined, GeoGebra and PjBL form a powerful educational synergy. GeoGebra supports the visualization and modeling needs of PjBL, allowing students to explore and present mathematical concepts within authentic projects. For instance, in project tasks involving geometry or function analysis, students can use GeoGebra to create models, test hypotheses, and present data in interactive forms. This combination fosters inquiry-based learning, promotes the integration of technology, and increases student autonomy and motivation (Setyawan et al., 2024).

Several empirical studies support this integration. For example, Bakar et al. (2021) found that the use of GeoGebra in mathematics classrooms significantly enhanced students' visual reasoning and fostered deeper engagement when integrated into exploratory learning activities. Similarly, research by Setyawan et al. (2024) reported positive effects on students' conceptual understanding and engagement when GeoGebra was used in collaborative PjBL environments. However, despite these promising outcomes, the practical implementation of this integration is often challenged by several factors, including limited teacher training, inadequate infrastructure, and insufficient curriculum alignment.

The Technological Pedagogical Content Knowledge (TPACK) framework (Mishra & Koehler, 2006) offers a useful lens to understand these challenges. Effective integration of GeoGebra into PjBL requires teachers to possess not only content knowledge and pedagogical skills but also technological expertise. Many teachers, however, lack sufficient TPACK, leading to ineffective or superficial use of technology in classrooms. In addition, the complexity of designing meaningful projects that align with curriculum goals while integrating technology adds to the instructional burden.

Furthermore, integrating GeoGebra with PjBL opens possibilities for interdisciplinary learning. In STEM education, for example, students can use GeoGebra to simulate engineering designs, visualize scientific phenomena, or model data, making mathematics more relevant and applied. This is reflected in hybrid models such as "PjBL + STEM + GeoGebra," which promote transdisciplinary skills and innovative problem-solving (Alihodžić et al., 2024). Other emerging approaches include "AR-PjBL + GeoGebra," which leverages augmented reality to enhance spatial reasoning and student engagement in geometry projects.

Given the growing demands for digital competencies and 21st-century learning outcomes, the integration of visualization tools like GeoGebra in PjBL has become not just relevant but essential. However, despite growing interest, there is a lack of synthesized evidence that critically evaluates how GeoGebra has been implemented within the PjBL framework and what outcomes and challenges have emerged. This gap highlights the need for a Systematic Literature Review (SLR) to consolidate current knowledge, identify trends, and guide future practices.

Research Method

This study employs a Systematic Literature Review (SLR) approach, guided by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol. An SLR is a rigorous method designed to collect, evaluate, and synthesize existing research evidence in a systematic, transparent, and replicable manner. It is particularly effective for gaining a comprehensive overview of empirical studies in a specific research area, identifying research gaps, evaluating methodological quality, and forming theoretical or practical recommendations (Moher et al., 2009; Siddaway et al., 2019).

The use of SLR in this study is motivated by the need to provide a reliable and replicable review of how GeoGebra has been implemented within the Project-Based Learning (PjBL) framework in mathematics education. Unlike traditional literature reviews, SLR minimizes researcher bias through predefined inclusion and exclusion criteria

and a documented review process. It allows for objective interpretation of findings and supports evidence-based decision-making (Siddaway et al., 2019).

PRISMA is chosen as the guiding protocol due to its structured and systematic process for identifying, screening, and including studies. PRISMA improves transparency in reporting reviews and enhances the reproducibility of the literature selection process, making it widely accepted in educational and health sciences research (Moher et al., 2009).

To carry out the SLR, this study adopts a six-stage process adapted from the model proposed by Perry & Hammond (2002), who developed a comprehensive framework specifically for systematic reviews in software and educational research:

The review process in this research consists of several sequential stages:

- (i) Formulate question clear and focused research,
- (ii) Search systematic to scientific literature,
- (iii) Filter and select articles based on criteria inclusion and exclusion that have determined,
- (iv) Synthesizing findings through qualitative analysis,
- (v) Evaluate the quality of selected studies, and
- (vi) Reporting findings in a structured manner

The main research questions asked in this study are:

1. How has GeoGebra been implemented in the Project-Based Learning (PjBL) framework in education mathematics?
2. What are the main results and challenges related to the implementation in previous studies in previous studies?

Based on the research questions, inclusion and exclusion criteria are created based on various categories, such as the table 1 below:

Table 1
Criteria Inclusion and Exclusion

Category	Inclusion	Exclusion
Topics	A study that discusses the use of GeoGebra in the Project-Based Learning (PjBL) model in mathematics learning.	Studies that only discuss GeoGebra without the involvement of PjBL, or only discuss PjBL without GeoGebra.
Publication Type	Scientific articles that have been published in peer-reviewed journals (empirical or review).	Non-scientific articles such as opinions, editorials, non-review proceedings, project reports, or blogs.
Publication Year	Articles published in the period 2020–2025.	Articles published before 2020.
Language	Articles are written in English or Indonesian.	Articles in languages other than English and Indonesian.
Educational Context	Focus on formal education (elementary school/middle school/high school/college) and mathematics subjects.	Focus on non-formal education, or subjects other than mathematics (such as physics or general science).
Article Access	Articles are available in full-text documents for thorough analysis.	Article not available in full access (abstract or preview only).
Relevance	Research shows the influence or application of GeoGebra in PjBL learning, including learning outcomes or evaluation.	The article does not discuss the results, implementation, or evaluation of GeoGebra in the context of PjBL or does not directly link the two.
Duplication	Unique articles in search results from the database.	Articles that are duplicates or appear more than once in different databases.

To gather relevant literature, this research conducted searches on four academic databases: Crossref, Google Scholar, Semantic Scholar, and Scopus, using keywords such as "GeoGebra", "Project-Based Learning", and "mathematics education". Initially, a total of 428 articles were collected using the Publish or Perish (PoP) software.

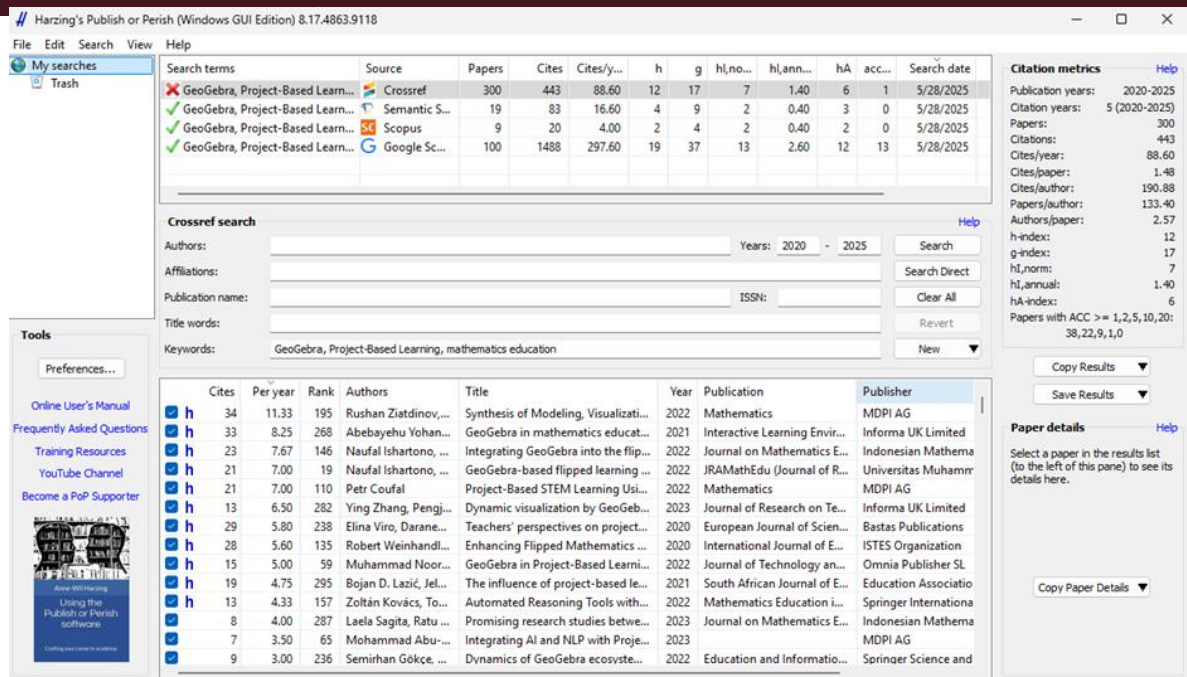


Image 1. Usage of PoP software to collect articles

The search results were then extracted from PoP and imported into Covidence, a web-based platform specifically designed to facilitate and manage Systematic Literature Reviews (SLRs). Covidence streamlines the entire review process—from importing references and removing duplicates, to screening titles/abstracts and reviewing full texts—by offering an intuitive interface and collaborative tools. It helps researchers work efficiently and maintain methodological transparency according to standards like the PRISMA framework.

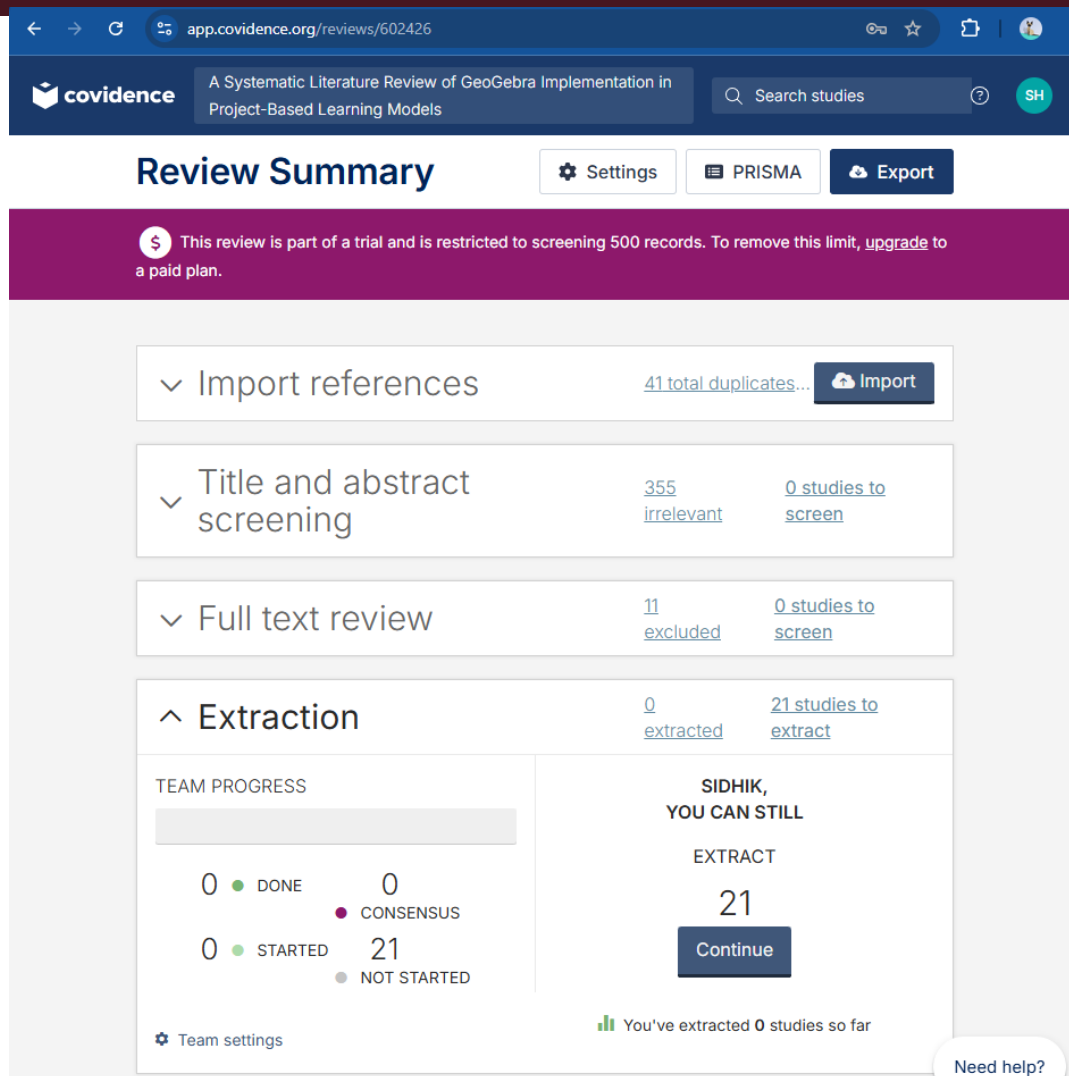


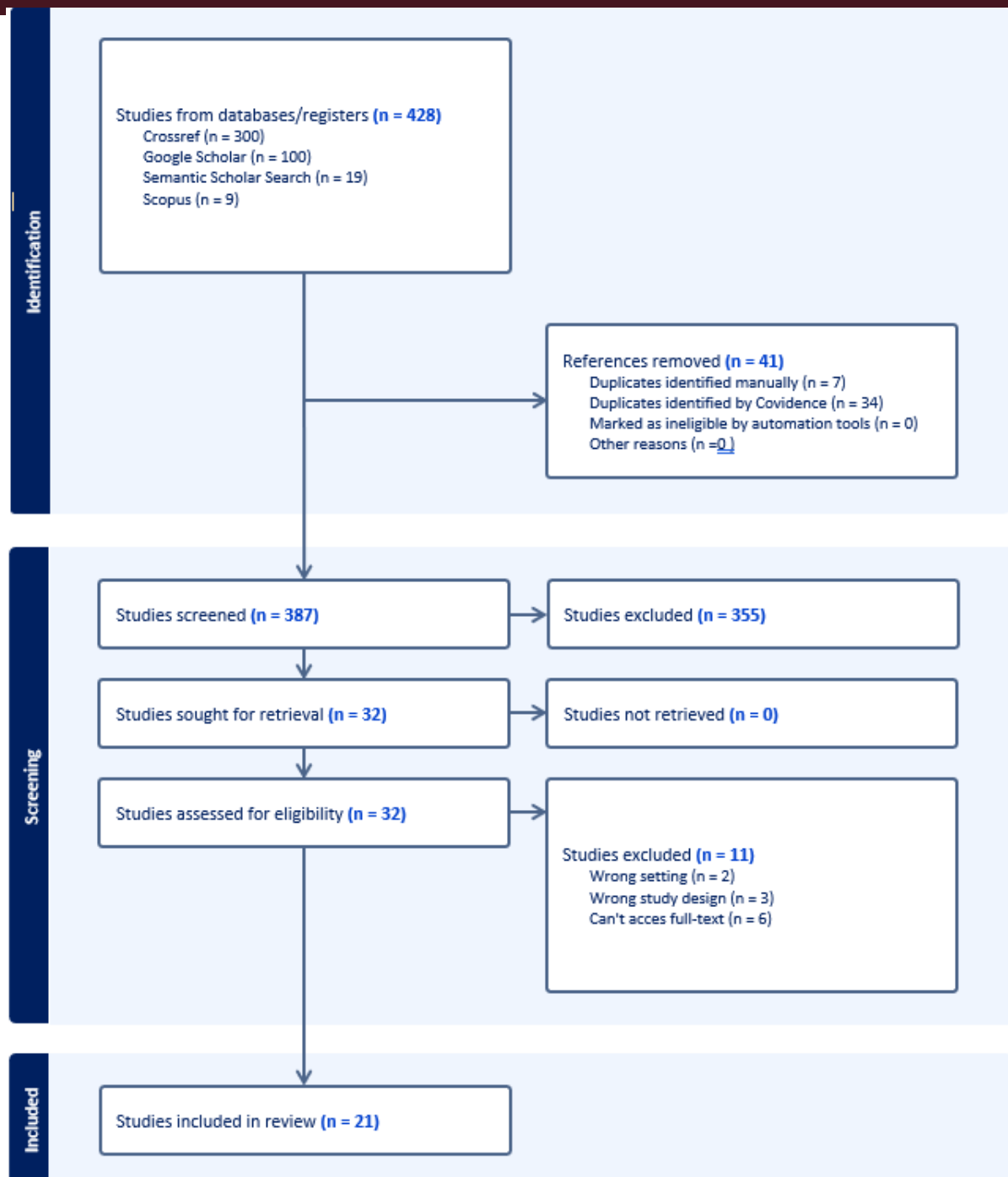
Image 2. Covidence interface showing article management process

Following the import, a deduplication process was conducted. A total of 41 duplicate articles were removed—7 duplicates were identified manually, while 34 were automatically detected and removed by Covidence—resulting in 388 unique articles proceeding to the next stage.

In the title and abstract screening phase, all articles were evaluated for relevance to the research focus. As a result, 355 articles were excluded for not meeting the inclusion criteria, leaving 33 articles for full-text review.

Next, the full texts of these 33 articles were assessed to determine their eligibility and methodological quality. The evaluation considered contextual relevance, study design, and accessibility of the full text. In this stage, 11 articles were excluded: 1 for lacking contextual alignment, 3 for irrelevant research designs, and 6 due to inaccessible full texts.

After completing all screening and filtering steps, a final set of 21 articles met all inclusion criteria. These articles form the analytical basis of this Systematic Literature Review, conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure a systematic, transparent, and replicable review process.



. Image 3. Exported PRISMA Flowchart

From the PRISMA protocol used , obtained as many as 21 subjects research that meets the requirements Terms and Conditions according to Table 1 , with description subjects study the can seen in Table 2 following This :

Table 2
Subject Study

No	Title	Authors	Published Year	Journal
1	Mathematical representation ability through geogebra-assisted project-based learning models	Septian , A ;	2020	Journal of Physics: Conference
2	GeoGebra in Project-Based Learning (Geo-PJBL): A dynamic tool for analytical geometry course	Kholid , MN; Pradana, LN; Maharani, S; Swastika, A	2022	JOTSE
3	Student's mathematical connection ability through GeoGebra assisted project-based learning model	Septian , A	2022	Journal Element
4	Exploring the potential use of GeoGebra augmented reality in a project-based learning environment: The case of geometry	Lainufar ; Mailizar , M; Johar, R	2021	Journal of Physics: Conference Series
5	Improving higher order thinking skills (hots) with project based learning (pjbl) model assisted by geogebra	Prananda , MR; Proboningrum , DI; ...	2020	Journal of Physics
6	Penerapan project based learning berbantuan aplikasi geogebra untuk meningkatkan berfikir kreatif matematis mahasiswa	Lusiana, V	2023	TEACHING: Journal Innovation Teaching and Science
7	Development of a web-based worksheet with a project-based learning model assisted by GeoGebra	Muchlis , EE; Priatna , N; ...	2021	Journal of Educational Research
8	Geogebra-assisted inductive reasoning in project-based learning through a web-based system	Muchlis , EE; Priatna , N; Herman, T; ...	2023	Journal of Engineering
9	Enhancing Students' Mathematical Critical Thinking Skills through a GeoGebra Integrated Project-Based Learning Model	Setyawan , D; Anas, A; Nasir, AM; ...	2024	Journal of Ecohumanism
10	Mathematical Problem-Solving Skills in View of Self-Efficacy in GeoGebra-Assisted Project-Based Learning	Rahmawati, L; Walid, W; Cahyono, AN		Continuous : Journal Study
11	Development of Project Based Learning Learning Model Assisted by Geogebra Software to Improve Students' Creative Thinking Ability at SMK N 1 Penanggalan	Cibro , B; Siregar, H; Rambe , IH	2021	Journal of Mathematics Technology
12	Implementation of the STEM-GeoGebra Integrated PjBL Model to Improve Student's Critical Thinking Skills	Rohmah, NS; Suryaningtyas , W; Holisin, I	2023	Journal of Education
13	Penerapan model pembelajaran project based learning berbantuan geogebra untuk meningkatkan hasil belajar siswa	Nurhayati, N; Zuhra, F; Salehha , OP	2021	Journal of Mathematics Education
14	Pengembangan pocket book digital berbasis project based learning menggunakan geogebra untuk meningkatkan pemahaman konsep matematis siswa SMP	Anjarwati , S ; ...	2022	Wilangan : Journal Innovation
15	Pembelajaran Berbasis Proyek Menggunakan Software Matematika	Hasibuan , NA; Yahfizam , Y	2024	Catalyst : Journal Knowledge

	Geogebra Terhadap Kemampuan Komputasi Siswa			
16	Studi Literatur: Kemampuan Berpikir Kreatif dalam Model Pembelajaran Project Based Learning dengan Bantuan Aplikasi Geogebra	Niswah, K; Exactics , T; ...	2024	PRISMA, Proceedings
17	Peningkatan kemampuan komunikasi matematis dengan model project based learning berbantuan geogebra: Solusi inovatif pendidikan modern	Lismayanti , N; Hutajulu , M; ...	2024	JPMI (Journal
18	PENERAPAN MODEL PEMBELAJARAN PROJECT BASED LEARNING BERBANTUAN GEOGEBRA UNTUK MENINGKATKAN HASIL BELAJAR SISWA	Nurhayati, Nurhayati; Zuhra, Fatma; Salehha , Osey Putri	2022	Journal of Mathematics Education (Jupitek)
19	Effects of the Geogebra-assisted Missouri mathematics project learning model on students mathematical communication ability	Kurniawan, Ilham; Ulfah, Syafika	2023	Journal of Mathematics Education Research
20	OPTIMALISASI KEMAMPUAN REPRESENTASI MATEMATIS SISWA MELALUI PROJECT-BASED LEARNING BERBANTUAN SOFTWARE GEOGEBRA	Ilma, Zakiya Aulia;	2021	JUDIKA (UNSIKA EDUCATION JOURNAL)
21	APPLICATION OF GEOGEBRA APPLICATION TO STUDENTS' GEOMETRIC THINKING SKILLS AND LEARNING INTERESTS THROUGH A PROJECT-BASED LEARNING MODEL	Hidayati , Penti ;	2024	International Journal of Multidisciplinary Research and Literature

Results and Discussion

The subjects in Table 2 above will be analyzed For answer question research mentioned in the chapter previously. Next is a summary from results 21 subject analyst:

Table 3
Subject Analysis Summary Study

No. Subject	Type of Study	GeoGebra Implementation	PjBL Model Used	Key Results	Challenges Encountered
1	Experimental study	Used For increase ability representation mathematics	PjBL with GeoGebra	Significant improvement in students' mathematical representation abilities	The need for student and teacher training in the use of GeoGebra
2	Experimental study	Geo- PjBL applied in class mathematics college tall	Geo- PjBL	Increase understanding concepts and skills collaborative	Management time projects and limitations device soft
3	Experimental study	For develop connection mathematical through PjBL	PjBL + GeoGebra	Student more capable to connect draft between material	Still found difficulty beginning student understand GeoGebra functions
4	Experimental study	GeoGebra combined with AR technology	AR- PjBL + GeoGebra	Interesting interest learn	Technology integration is quite complex and requires IT support.

		in learning project		and strengthen visualization	
5	Experimental study	Used For improve HOTS through approach project	PjBL + Geogebra	Used For improve HOTS through approach project	Used For improve HOTS through approach project
6	Experimental study	Used in post-test evaluation of learning PjBL	PjBL + GeoGebra	Increase results Study mathematics	Need comparison explicit between PjBL+GeoGebra and without
7	Study developer	GeoGebra is used in 4D model for geometry field	PjBL + GeoGebra	feasible model used by students	Not yet explained its effectiveness in scale big
8	Quantitative study	Used For facilitating 34 students mathematics	PjBL with GeoGebra	The results show approach succeed connect material	Not explained challenge specific
9	Qualitative study	Integrated in pedagogy mathematics	PjBL + GeoGebra	Providing positive implications for mathematics teaching strategies	Not mentioned in a way explicit
10	Experimental study	Used For increase breakdown problems and <i>self-efficacy</i>	PjBL + GeoGebra	Very effective For student with self-efficacy tall	Not clear the impact on students with self-efficacy low
11	Experimental study	Used in the PjBL model For oppose assumption negative to mathematics	PjBL with GeoGebra	Effective increase interest Study	Need adaptation technology
12	Experimental study	Integrated with STEM in learning models	PjBL + STEM + GeoGebra	Increase understanding draft mathematics in a way comprehensive	Complexity integration cross discipline
13	Experimental study	Used For increase results Study mathematics	GeoGebra in PjBL	Learning outcomes increase with this model	Student motivation is the key to success
14	R&D Research	Produce book digital pocket based PjBL with GeoGebra	PjBL + GeoGebra	Facilitating understanding of mathematical concepts in junior high school	Need testing carry on about effectiveness wide

15	Descriptive study	The use of digital technology and GeoGebra in mathematics learning	PjBL with GeoGebra	Increase enthusiasm and ability student in Study mathematics	Readiness infrastructure school
16	Experimental study	GeoGebra is used in learning think creative mathematical	PjBL with GeoGebra	Increase ability think creative student	Still a little research similar
17	Experimental study	Used in strengthening mathematical communication skills	PjBL + GeoGebra	Mathematical communication improved significantly	Not mentioned in a way explicit
18	Quasi-experimental study	Used for SPLDV material for high school students	PjBL + GeoGebra	Improvement significant on the results Study student	Not mentioned constraint
19	Experimental study	GeoGebra is used in the Missouri Mathematics Project (MMP) model	PjBL + MMP + GeoGebra	Improving mathematical communication skills in the moderate category	Limitations generalization results
20	Quasi-experimental study	GeoGebra is used For compare results representation mathematical	PjBL + GeoGebra	Mathematical representation ability is higher than ordinary learning	Need training more carry on for teachers
21	Experimental study	GeoGebra is used in learning geometry For increase interests and abilities think	PjBL + GeoGebra	Ability think geometric and interest Study student more tall than learning conventional	Not mentioned in a way explicit

To provide further clarification on how GeoGebra is integrated into Project-Based Learning (PjBL), a classification of terminology was made based on how the model and the tool are combined. Table 3 presents a description of the terms used in the "PjBL Model Used" column. This table helps to avoid ambiguity in interpretation by clearly defining the intended relationship between the PjBL model and the use of GeoGebra in each study. Understanding this classification allows readers to better grasp the extent of integration, whether GeoGebra is merely a supporting tool or more deeply embedded in the learning model. It also facilitates comparative analysis among studies using different approaches to technology integration in project-based learning contexts.

Table 4
PjBL Model Used Column Description

Term	Explanation	Special Characteristics
PjBL + GeoGebra	PjBL is applied as the main model, and GeoGebra is used as a visualization or concept exploration tool.	GeoGebra is only a supporting tool ,not part of the model structure.

PjBL with GeoGebra	Similar meaning to “PjBL + GeoGebra”, used interchangeably.	More flexible, emphasizing togetherness but not always indicating deep integration.
Geo-PjBL	It is a hybrid model that explicitly integrates GeoGebra into all stages of PjBL.	GeoGebra is integrated into the PjBL design as an essential part of the exploration, investigation, etc. phases.
AR-PjBL + GeoGebra	PjBL model that utilizes Augmented Reality technology plus the use of GeoGebra.	Multi-technology: project learning assisted by AR for real visualization and GeoGebra for concepts.
PjBL + STEM + GeoGebra	A combination of project-based learning, STEM cross-disciplinary integration, and the help of GeoGebra.	Complex: cross-disciplinary and requires high pedagogical and technological skills.
GeoGebra in PjBL	Placement of GeoGebra as the main media in one phase or aspect of PjBL activities.	Typically used in the exploration or presentation phase of a project, but not fully integrated.
PjBL + MMP + GeoGebra	The project learning model is combined with the Missouri Mathematics Project and the use of GeoGebra.	Focus on the MMP stages (exploration, discussion, practice) in the PjBL structure with the help of GeoGebra.

Conclusion and Suggestion

This systematic literature review of 21 scientific articles demonstrates that the integration of GeoGebra within the Project-Based Learning (PjBL) framework has been implemented through diverse and innovative models. The most common forms include “PjBL with GeoGebra,” where GeoGebra is utilized primarily as a visualization and exploration tool to support mathematical concepts. More integrative models, such as “Geo-PjBL,” combine GeoGebra with the core structure of the PjBL model to deepen conceptual learning and interactive engagement.

Several articles highlight the potential of combining GeoGebra with interdisciplinary learning frameworks, including STEM, augmented reality (AR), and multimedia modules (MMP). For instance, models like “PjBL + STEM + GeoGebra” encourage students to complete real-world projects that require integrating knowledge from science, technology, engineering, and mathematics using GeoGebra’s dynamic tools. Meanwhile, models such as “AR-PjBL + GeoGebra” enhance students’ spatial reasoning through interactive visual environments, and “PjBL + MMP + GeoGebra” promote deeper engagement through rich, multimedia-based project materials.

Across the reviewed studies, GeoGebra plays several key roles: (1) dynamic visualization of abstract mathematical concepts, (2) development of multi-modal representations (graphs, diagrams, simulations), (3) enhancement of conceptual understanding, and (4) promotion of student engagement, collaboration, and independent exploration. These implementations consistently show positive effects on students’ mathematical achievement, especially in improving conceptual understanding, mathematical representation skills, and higher-order thinking abilities (HOTS).

However, several challenges are also identified. The lack of technological readiness and literacy among teachers and students often hinders effective GeoGebra use. Additionally, limited access to devices, software compatibility, and internet infrastructure can reduce the feasibility of applying GeoGebra-based projects in certain educational contexts. Another challenge is time management and planning for project activities, especially for educators who are still new to PjBL methodologies. Integrating additional technologies such as AR or STEM frameworks increases the complexity and requires structured curriculum adaptation.

For future practice and research, several suggestions can be proposed:

- Capacity building for educators is essential through training and continuous professional development focused on effective use of GeoGebra and PjBL strategies.
- Infrastructure improvement should be prioritized to ensure equitable access to the technology necessary for dynamic learning environments.

- c. Curricular and pedagogical alignment is needed to embed GeoGebra meaningfully into interdisciplinary and technology-supported projects.
- d. Progressive implementation is recommended, beginning with simple applications before expanding to more complex integrations like AR or STEM-based PjBL.
- e. Researchers and educators are encouraged to utilize tools such as Covidence, a web-based platform that supports systematic literature reviews, for organizing references, screening articles, and managing evidence-based implementation processes.

In summary, despite some practical challenges, GeoGebra's integration in the PjBL model offers significant potential to transform mathematics education by fostering visualization, critical thinking, and collaborative learning, all essential competencies for 21st-century learners.

References

- Aisy, N. M. R., Mulyono, & Walid. (2022). Analysis of students' difficulties in mathematics problem-solving ability on number pattern material. *Jurnal Pijar MIPA*, 17(6), 706–711.
- Alihodžić, B., Atanasova-Pachemska, T., & Nesimović, S. (2024). Attitudes of high school students towards visualization of mathematical content. *International Electronic Journal of Mathematics Education*.
- Arsyad, M., Mujahiddin, & Syakhrani, A. W. (2024). The efficiency of using visual learning media in improving the understanding of science concepts in elementary school students. *Indonesian Journal of Education (INJOE)*, 4(3), 775–787.
- Bakar, M. N. A., Rosli, R., & Mohd, T. (2021). Exploring the effectiveness of GeoGebra-assisted learning in enhancing mathematical visualization skills. *Eurasia Journal of Mathematics, Science and Technology Education*, 17(3), em1945.
- Bell, S. (2010). Project-based learning for the 21st century: Skills for the future. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas*, 83(2), 39–43.
- Bruner, J. S. (1966). *Toward a theory of instruction*. Harvard University Press.
- Cruz, S., Viseu, F., & Lencastre, J. A. (2022). Project-based learning methodology as a promoter of learning math concepts: A scoping review. *Frontiers in Education*, 7, 953390.
- Harzing, A. W. (2010). *The Publish or Perish Book: Your guide to effective and responsible citation analysis*. Tarma Software Research.
- Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, 108(6), 1017–1054.
- Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & The PRISMA Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLOS Medicine*, 6(7), e1000097. <https://doi.org/10.1371/journal.pmed.1000097>
- Paivio, A. (1986). *Mental representations: A dual coding approach*. Oxford University Press.
- Panjaitan, S. M. (2024). Developing mathematical thinking with GeoGebra. *Journal of Mathematics and Learning*, 8(2), 145–158.
- Panjaitan, M. (2024). Implementation of GeoGebra as a mathematics learning medium by applying a problem-based learning model (PBM). *Edumaniora: Jurnal Pendidikan dan Humaniora*, 3(2), 59–66.
- Rifat, M., Sudiansyah, & Imama, K. (2024). Role of visual abilities in mathematics learning: An analysis of conceptual representation. *Al-Jabar: Jurnal Pendidikan Matematika*, 15(1), 87–97.
- Setyawan, D. ., Anas, A. ., Nasir, A. M. ., & Fadly, D. . (2024). Enhancing Students' Mathematical Critical Thinking Skills through a GeoGebra Integrated Project-Based Learning Model. *Journal of Ecohumanism*, 3(8), 8017 –. <https://doi.org/10.62754/joe.v3i8.5419>
- Siddaway, A. P., Wood, A. M., & Hedges, L. V. (2019). How to do a systematic review: A best practice guide for conducting and reporting narrative reviews, meta-analyses, and meta-syntheses. *Annual Review of Psychology*, 70, 747–770. <https://doi.org/10.1146/annurev-psych-010418-102803>
- Thomas, J. W. (2000). *A review of research on project-based learning*. The Autodesk Foundation.