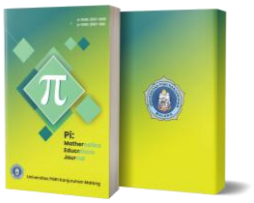
Pi: Mathematics Education Journal
e-ISSN: 2597-6915 p-ISSN: 2597-5161
Vol. 9, No. 1, 2026 | Pp. 63 – 74



GeoGebra Applets as Double Edged Tools for Visualization and Reasoning in Technology Based Mathematics Learning

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ARTICLE HISTORY
Received:
February, 09, 2026

Revised:
April, 24, 2026

Published:
April 30, 2026

Keywords:
GeoGebra Applet
Mathematical Visualization
Technology Based Learning

ABSTRACT

Although GeoGebra applets are widely used in technology-based mathematics learning, their implementation still faces limitations in optimally supporting students' visualization and mathematical reasoning. This study aims to analyze their utilization, challenges, and impact on students' mathematical thinking. A Systematic Literature Review (SLR) was conducted using the Publish or Perish (PoP) application by retrieving articles from Google Scholar and Scopus published between 2020 and 2025, based on predefined inclusion criteria. The review followed the PRISMA framework. Out of 263 identified articles, 20 studies were selected for in-depth analysis. The findings reveal that GeoGebra applets are predominantly implemented in higher education and junior high school contexts, particularly in geometry topics that require strong visual representation. The use of GeoGebra applets contributes positively to students' conceptual understanding, visualization ability, mathematical reasoning, and higher-order thinking skills (HOTS), especially when integrated with interactive and student-centered learning approaches. However, several challenges remain, including limited technological facilities, varying levels of teacher competence, insufficient student readiness, and the tendency to emphasize technical features over conceptual reasoning. Therefore, this study underscores the importance of designing pedagogical strategies that integrate GeoGebra applets with structured learning activities to explicitly foster students' mathematical reasoning rather than merely serving as visualization tools.

How to Cite: Raharjo, E. P., Mardiyana, M., Riyadi, R., Yunianto, W., & Adnan, M. (2026). *Geogebra Applets As Double Edged Tools For Visualization And Reasoning In Technology Based Mathematics Learning. Pi: Mathematics Education Journal, 9*(1), 63-74. https://doi.org/ 10.21067/pmej.v9i1.13893

1. Introduction

This article contains scientific papers in mathematics education. Students in mathematics education often face difficulties in developing strong visualization and

reasoning skills, particularly when learning abstract concepts. This challenge highlights the need for instructional approaches that support meaningful and conceptually rich learning experiences. This effort is realized through the "Merdeka Belajar" policy, which serves as the foundation for the development of the "Merdeka Curriculum," with a meaningful, contextual, and relevant learning orientation tailored to student needs [1]. Merdeka Belajar adopts constructivist principles that position students as active subjects in constructing knowledge through experience and interaction with the learning environment. Meanwhile, teachers act as facilitators, designing meaningful learning environments, encouraging student-centered learning, project-based learning, and flexible assessment practices. Although digital media can enhance learning, many students still struggle with mathematical reasoning and understanding abstract concepts. This issue is influenced by the dominance of conventional teaching approaches that emphasize procedural skills over conceptual understanding, highlighting the need for more interactive and visualization based learning tools [2]. One of the digital media with great potential in mathematics learning is GeoGebra, developed in 2001 by Markus Hohenwarter (Australia, born June 24, 1976), a mathematician at Johannes Kepler University (JKU) Linz. The GeoGebra program can be downloaded at www.geogebra.com.

The ease of technological access where GeoGebra is available for free on various platforms (web, desktop, mobile). GeoGebra is dynamic mathematics software that allows the visualization, construction, and exploration of two and three dimensional mathematical objects, and various interactive features known as GeoGebra Applets [3]. Geogebra applets can be used as visualization tools, discovery tools, and constructive media on a variety of mathematical topics [4]. Through the interactivity offered, students can observe the transformation of mathematical objects directly, explore the relationships between concepts, and build understanding independently [5]. The use of GeoGebra in mathematics learning has also been shown to have a positive impact on students' learning interest. Students' responses to the use of GeoGebra significantly influence their learning interest, where improved student responses are followed by an increase in learning interest. Furthermore, the coefficient of determination of 47.5% indicates that students' responses contribute substantially to their learning interest in mathematics learning[6].

Actual conditions on the ground, particularly in Indonesia, demonstrate a gap between GeoGebra's potential and its implementation in mathematics learning. GeoGebra's use remains relatively limited, primarily due to teachers' low technological competence, limited digital learning facilities and infrastructure, and a tendency to use ready-made GeoGebra Applets without adapting them to students' needs [7][8]. In contrast, previous studies indicate a consistent pattern that GeoGebra Applets contribute positively to mathematics learning, particularly in terms of validity, practicality, student engagement, and support for visualization of abstract concepts. However, differences appear in the focus of each study: some emphasize media validity and practicality, while others highlight student creativity and motivation through interactive and real-time visualization features. Therefore, despite these benefits, several gaps remain, such as the limited evaluation of effectiveness in improving higher-order thinking skills and the need for broader implementation across different mathematical topics and learning contexts [9]-[11].

Previous studies remain limited in providing a comprehensive analysis of GeoGebra Applets across educational levels, as most research focuses on a single topic or level. This study utilizes a Systematic Literature Review (SLR) to gather, assess, and synthesize existing research on the application of GeoGebra Applets in mathematics teaching. This research details trends in the utilization of GeoGebra Applets across several grade levels, their impact on students' ability to conceive and reason mathematically, and the problems

encountered throughout their implementation. This study utilizes the SLR technique to elucidate the advantages and disadvantages of employing GeoGebra Applets as a dual-purpose instrument in technology enhanced mathematics education, aiming to offer both theoretical and practical insights.

2. Methods

This research use a systematic literature review (SLR) to tackle an issue by discovering, critically assessing, and synthesizing data from several pertinent, high-quality individual studies that address one or more research questions [12]. The data collection process was conducted using the Publish or Perish (PoP) application by searching two major databases, namely Google Scholar and Scopus, which were selected to ensure broad coverage and access to high-quality indexed publications, despite potential limitations such as data redundancy and restricted indexing. To enhance the comprehensiveness and transparency of the search strategy, multiple keywords and Boolean operators were used, including "GeoGebra Applet", "GeoGebra AND mathematics learning", "GeoGebra AND visualization", and "GeoGebra AND mathematical reasoning". The search was limited to publications from 2020 to 2025, resulting in 263 documents (200 from Google Scholar and 63 from Scopus), which were then filtered using inclusion and exclusion criteria to ensure their relevance, quality, and consistency with the research objectives.

Table 1. Inclusion And Exclusion Criteria

Criteria	Inclusion	Exclusion
Article Type	Peer reviewed scientific articles related to the research topic	Theses, editorials, opinions, non-scientific articles
Topic / Focus	GeoGebra Applet in mathematics learning	Articles unrelated to the topic
Language	English or Indonesian	Other languages
Publication Year	2020–2025	Publication year outside the research period
Educational level	Elementary School – University	Educational level beyond target
Access / Full Text	Full text and open access available	Full text and open access are not available.
Type of Study	Primary research or empirical research articles	SLR / previous reviews, books, non-academic sources
Duplication	No duplicate	Duplication

The research questions (RQs) formulated according to the chosen focus topic in this study are as follows:

RQ_1 : What are the forms and characteristics of GeoGebra Applets used to support the visualization of mathematical concepts and the development of students' reasoning skills in schools, based on published research results?

RQ_2 : What is the impact of GeoGebra Applets on visualization and students' mathematical reasoning skills in mathematics learning?

RQ_3 : What are the challenges in using GeoGebra Applets as a double edged tool in mathematics learning?

This study adhered to the PRISMA procedure to improve transparency and rigor in data reporting, comprising four stages: identification, screening, eligibility, and inclusion. During the identification phase, articles were obtained from designated databases utilizing predetermined search terms. During the screening process, duplicate and irrelevant studies

were eliminated based on their names and abstracts. During the eligibility phase, full-text publications were evaluated according to the predetermined inclusion and exclusion criteria. Ultimately, during the inclusion phase, only papers that satisfied all criteria were chosen for subsequent analysis. Research inclusion is the final phase in the PRISMA system, which also encompasses screening and eligibility [13].

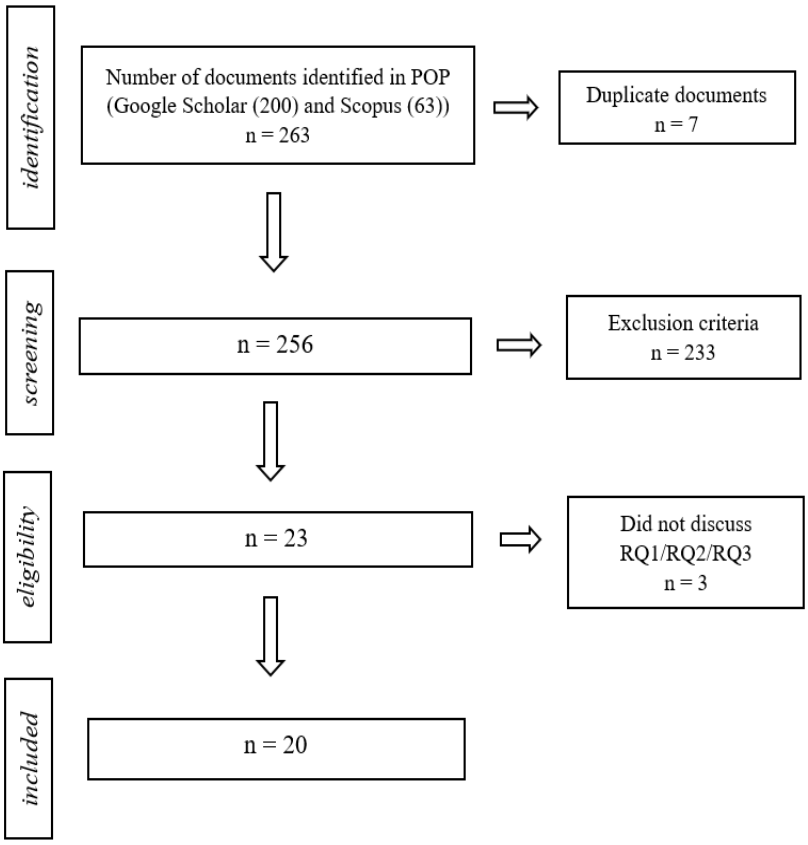

Figure 1. PRISMA Flowchart

A total of 20 articles that met all PRISMA stages were selected as the main sources for analysis. This number is considered adequate, as the selected studies represent diverse educational levels, research contexts, and findings related to the forms, impacts, and challenges of using GeoGebra Applets in mathematics learning, thereby providing sufficient and representative evidence to support the conclusions of this study.

3. Result and Discussion

3.1. This Forms and Characteristics of GeoGebra Applet Utilization

Based on an analysis of the 20 articles reviewed, the use of GeoGebra Applets was most frequently found at the junior high school (SMP) and university levels, with five articles. At this level, they facilitate students' comprehension of abstract ideas via dynamic visuals, including geometry, functions, and algebra. Moreover, the application of GeoGebra Applets at the senior high school (SMA) level was identified in four papers, utilized not just for visualization but also to facilitate the discovery of intricate ideas and mathematical analysis. At the elementary school (SD) level, three papers examined the application of GeoGebra, emphasizing the tangible and participatory presentation of fundamental mathematical ideas.Three papers did not precisely specify the educational attainment of the research subjects. These articles focused more on the development of GeoGebra Applets in general without specifically addressing specific educational levels.

The dominant use of GeoGebra Applets at the junior high school and university levels indicates that this medium is widely used at learning stages that require strengthening visualization and understanding of abstract concepts [14]-[17]. A summary of this distribution across educational levels is presented in Figure 2.

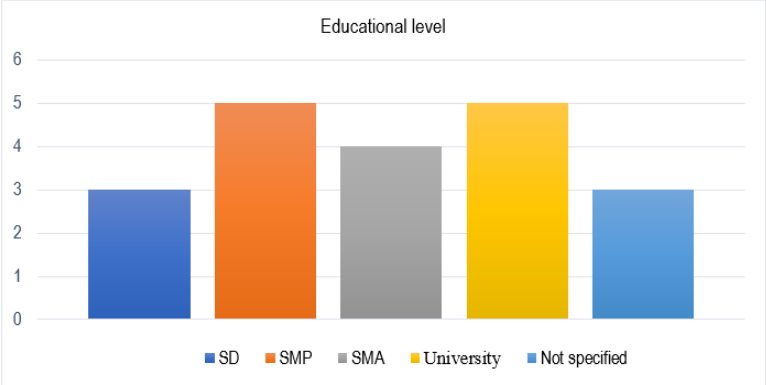

Figure 2. Educational Levels for Using Geogebra Applets

Based on the distribution of publication years, most articles related to the use of GeoGebra Applets were published between 2022 and 2024, with the highest number of publications occurring in 2024. This trend indicates a growing interest among researchers in integrating GeoGebra Applets into technology based mathematics learning. The increase in publications during this period reflects the rapid development of digital learning tools and the growing emphasis on interactive and visual learning environments in mathematics education. Furthermore, this upward trend indicates that GeoGebra Applets are increasingly recognized as effective tools to support students' mathematical visualization, conceptual understanding, and reasoning skills. However, at the visualization stage, students are generally able to identify problems and objectives using the language presented in the tasks, yet they are not fully capable of implementing appropriate strategies, reviewing their solutions, or evaluating and exploring alternative strategies [18]. The distribution of publication years related to the use of GeoGebra Applets is illustrated in Figure 3.

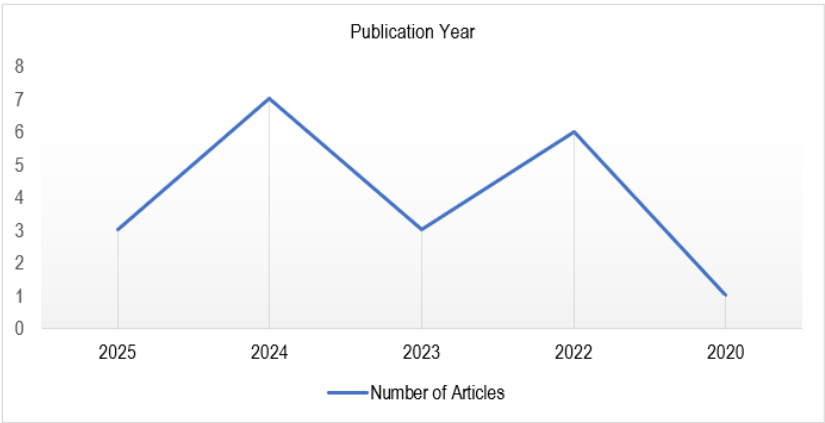

Figure 3. Publication Year of Geogebra Applet Utilization

Based on an analysis of 20 articles, geometry was the most widely studied topic, encompassing plane geometry, spatial geometry, circles, and nets. The choice of geometry as the primary focus for utilizing the GeoGebra Applet is inseparable from the characteristics of geometry, which requires strong visualization, representation, and spatial

understanding skills [3][5][7][19]. An overview of the material distribution is presented in Figure 4.

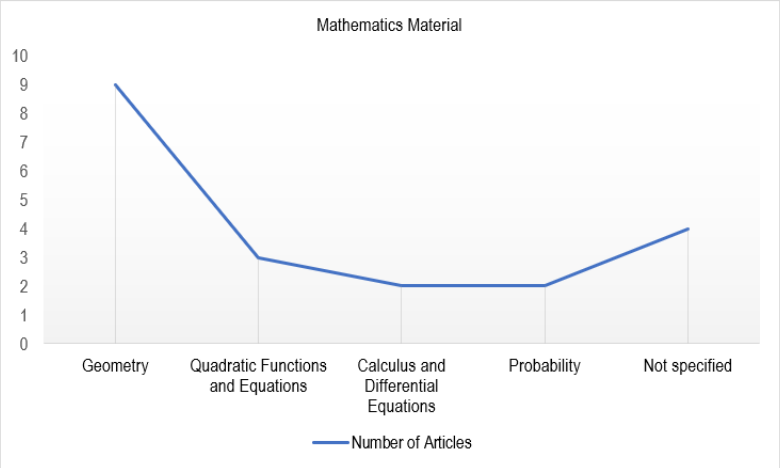

Figure 4. Material for Utilizing Geogebra Applets

The use of GeoGebra Applets in areas such as functions, calculus, and probability remains comparatively restricted, hence presenting prospects for further development and study over a broader spectrum of mathematical subjects. The application of GeoGebra Applets in mathematics education exhibits significant variability and is tailored to specific learning objectives. Moreover, in addition to incorporating technology into education, academic institutions must also cultivate important talents to equip future generations for forthcoming problems. One such measure is to design strategies that promote the cultivation of pertinent abilities[20]. As summarized in Table 2.

Table 2. Results of the Literature Review

No	Title	Writer	GeoGebra Applet Utilization Form
1	*GeoGebra Applets and Gemini Artificial Intelligence in Separable Variable Differential Equations in Engineering Students of Antofagasta Chile*	[10]	Visualization and Representation
2	*Geogebra Applets And Homework Tasks To Help Engineering Students With 3D Visualization In A Multivariable Calculus Course*	[21]	
3	*Development of Geo-Math Application by Integrating Geo-Gebra Applets to Improve Students' Spatial Ability*	[22]	
4	Pelatihan Pembuatan Media Pembelajaran Geogebra Bagi Guru Matematika Sekolah Menengah Pertama Kota Mataram	[23]	
5	Media Pembelajaran Lingkaran Berbasis Geogebra Applet Untuk Penguatan Kemampuan Berpikir Kreatif Melalui Pembelajaran *Open Ended*	[24]	

6	Pengembangan Applet GeoGebra pada Materi Distribusi Peluang Khusus	[9]	
1	*Learning trajectory to teach double integrals with GeoGebra Applets*	[3]	Concept Exploration and Problem Solving
2	*Learning the Parabola Mediated by Problem-Solving, Semiotic Representations, and Applets in GeoGebra*	[25]	
3	Kualitas Pembelajaran Model *Discovery Learning* Berbantuan Applet GeoGebra terhadap Kemampuan Penalaran Matematis Siswa dalam Menyelesaikan Soal HOTS	[14]	
4	*Problems and challenges of using randomized automatically evaluating geometric construction problems in Moodle LMS*	[19]	
1	*Enhancing Spatial Reasoning in Geometry: The Role of Cooperative Learning Assisted by the GeoGebra Applet*	[5]	Supporting the Implementation of Learning Models
2	*Validity Of Guided Inquiry-Based Learning Instrument With Geogebra Applets For Teaching Circles*	[26]	
1	Pengembangan Applet Geogebra Materi Jaring-Jaring Bangun Ruang Untuk Siswa Sekolah Dasar	[7]	Development of Interactive Learning Media
2	*Development Of Online Interactive Learning Media Using Geogebra Applet On Probability*	[15]	
3	*Development of GeoGebra Applets of Equation and Square Functions for Class IX Students of Junior High School*	[27]	
4	*STEM oriented mathematics learning with GeoGebra*	[28]	
1	*Student Creativity in Creating GeoGebra Applet for Quadratic Function Material*	[11]	Teacher or Student Creativity and Empowerment
2	Pelatihan Pembelajaran HOTS Sejak Dini Dengan Menggunakan Applet Geogebra Di SD Swasta Islam Terpadu Deli Insani	[29]	
1	*Problems and challenges of using randomized automatically evaluating geometric construction problems in Moodle LMS*	[19]	Digital Technology Assessment and Integration

2	*A Constructionist Approach To Learning Computational Thinking In Mathematics Lessons*	[16]

Based on Table 2, the use of GeoGebra Applets can be categorized into several main themes, including visualization and representation, concept exploration and problem solving, learning model support, interactive media development, creativity enhancement, and technology integration. The findings show a dominant focus on visualization and representation, indicating that most studies emphasize helping students understand abstract mathematical concepts, as shown in Figure 5.

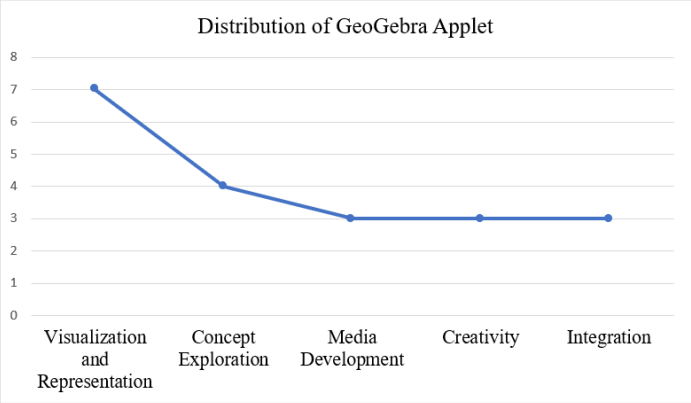

Figure 5. Distribution of GeoGebra Applet Utilization in Mathematics Learning

However, fewer studies integrate visualization with mathematical reasoning development. In addition, limited research examines the effectiveness of GeoGebra based media in improving higher order thinking skills. Moreover, GeoGebra Applets have been shown to improve learning outcomes, as a study reported higher mathematical reasoning achievement using Discovery Learning assisted by GeoGebra (79.84 > 62.11), supporting its contribution to HOTS development [14].

3.2. Impact of Using Geogebra Applet

The use of GeoGebra Applets in technology-based mathematics learning has been widely studied because of its potential to support students' visualization, conceptual understanding, and mathematical reasoning.

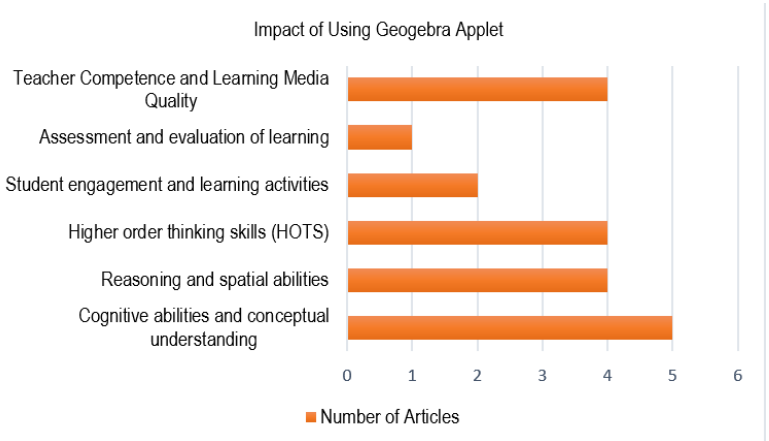

Figure 6. Impact of Using Geogebra Applet

According to the study presented in Figure 5, the utilization of GeoGebra Applets markedly enhanced conceptual comprehension, reasoning and spatial thinking abilities, as

well as higher-order thinking skills (HOTS). GeoGebra Applets serve as dynamic visualization and representation tools that assist students in constructing mathematical concepts more effectively through visualization, simulation, and modeling. This finding is supported by [24] who stated that GeoGebra Applets have a high level of validity and practicality and are able to increase student engagement and independence in learning. Furthermore, [22] demonstrated that the use of GeoGebra Applets on geometry and transformation materials is effective in improving spatial skills through direct interaction and manipulation of mathematical objects. Overall, GeoGebra Applets have a positive impact on visualization, reasoning, and HOTS in technology based mathematics learning. However, as a double-edged tool, their use requires appropriate pedagogical planning so that robust visualizations truly support mathematical reasoning, not just technical exploration.

3.3. Geogebra Applet as a Double Edged Tool

The utilization of GeoGebra Applets in mathematics education demonstrates its dual nature, offering both advantages and obstacles. The utilization of GeoGebra Applets in mathematics education offers substantial educational advantages while also posing implementation obstacles.

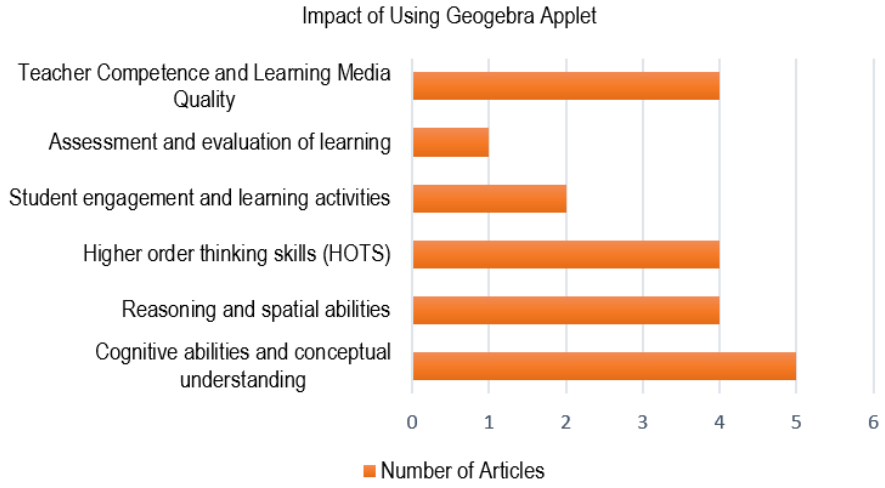

Figure 7. Challenges in Using Geogebra Applets

On the one hand, GeoGebra's dynamic visualizations and interactivity can help students build conceptual understanding and mathematical reasoning through more concrete representations. However, on the other hand, various obstacles arise, such as limited infrastructure and technical issues, difficulties in accurately representing certain mathematical concepts, and differences in teacher competency in integrating applet features into learning strategies. Challenges are also evident in student readiness, variations in learning styles, and the applicability of applets to the curriculum context. These conditions indicate that without careful pedagogical design, the use of GeoGebra Applets has the potential to shift the focus of learning from mathematical reasoning to purely technical exploration. Nevertheless, when implemented appropriately, GeoGebra Applets not only support student understanding but also improve the quality of interactive and innovative technology-based mathematics pedagogy and learning [23]

4. Conclusion

The findings of the 20 article systematic literature review (SLR) indicate that GeoGebra Applets function as double edged tools in technology-based mathematics learning. They are widely applied to support the visualization of abstract mathematical

concepts, particularly in geometry and related topics, thereby facilitating students' conceptual understanding and spatial reasoning. In addition, several studies report their positive contribution to the development of higher-order thinking skills (HOTS) through interactive and dynamic representations. However, the review also reveals several challenges in their implementation, including technical constraints, differences in teachers' digital competencies, and the tendency for learning to shift from mathematical reasoning to technical operations. Therefore, these findings highlight the importance of well designed pedagogical strategies to ensure that GeoGebra Applets are used effectively to enhance learning outcomes while minimizing their limitations.

Thank You Note

This article was written thanks to the assistance, guidance, and support of various parties. Therefore, the author expresses his deepest gratitude to Prof. Dr. Mardiyana, M.Si. and Dr. Riyadi, S.Pd., M.Si., as supervisors at Sebelas Maret University, for their guidance, input, and motivation throughout the writing process. In addition, appreciation is extended to Wahid Yunianto, PhD Student at Johannes Kepler University of Linz, and Assoc. Prof. Dr. Mazlini Adnan, Faculty of Science and Mathematics, Sultan Idris Education University, Malaysia, for their valuable academic support and contributions to this work. The author also sincerely thanks his family and friends for their continuous moral support and prayers.

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