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Development and Integration of GeoGebra Applets in Mathematics Learning

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ABSTRACT

Mathematics is a material that students consider difficult because its concepts are abstract. To overcome this, one approach that can be used is using technology-assisted learning. GeoGebra applet is a technology that is commonly used in mathematics. However, a few studies have discussed the relevance of this study to further research related to GeoGebra applets in mathematics and explore its potential. Therefore, this article discusses the development and integration of GeoGebra Applets in Mathematics Learning. The aim of this research is to investigate the relevance of the study to further research related to GeoGebra applets in mathematics and discuss the potential of these applets in enhancing students' ability in mathematics learning. The research method used is the Systematic Literature Review method, which analyses articles from 2013 to 2022. The research results show that GeoGebra Applets have been developed in various forms, including applications, ebooks, and assignment applications. The most commonly discussed learning material is geometry, with the potential for further research on other materials. GeoGebra Applets have been proven to help improve students' understanding, representation, problem-solving, and critical and spatial thinking skills in mathematics learning. This application positively contributes to the quality of mathematics learning through various forms of learning, including independent, direct, and innovative learning.

Introduction

Education is the right of every human being and is useful for facing the challenges and developments of the times. Education does not always have to be done through educational institutions. There are several types of education, all of which play a role in forming a complete human being. The types of education consist of formal, informal, and non-formal education. Formal education is education whose programs and activities are designed by official institutions, such as training institutions, workplaces, and educational institutions. Formal education provides certificates to participants who have completed programs or activities.

Furthermore, informal education is education related to daily activities and does not have a formal structure, for example, education in the family, work environment, or tourism. Lastly, non-formal education is education that has an activity program but is not officially evaluated, and participants do not receive a certificate at the end of the activity program. These types of education form a unified learning process that humans go through and shape humans to become better.

Regarding formal education, various subject matters are studied, one of which is mathematics. Mathematics material is studied at all levels of formal education, from elementary school to university level. Within the formal education framework, mathematics learning is a learning process that invites students to understand concepts and apply and develop mathematical concepts in a structured and systematic way.

Mathematical concepts mean abstract ideas a person has so that the person can determine or differentiate examples from non-examples. The concepts studied in mathematics are useful for mathematical knowledge, support the progress of science and technology in general, and serve as tools to solve everyday life problems. Studying mathematical concepts also means developing problem-solving abilities and analytical thinking so that a strong foundation of knowledge is built, which plays an important role in various aspects of life.

In studying mathematical concepts, students often experience difficulties, which can be conceptual, related to daily life, use of inappropriate learning methods, lack of motivation, anxiety, lack of understanding of prerequisite material, and so on. As stated, some students are less interested in mathematics because it is difficult and stressful. Apart from that, it also states that teaching mathematics requires methods and approaches that can accommodate the characteristics, abilities, and potential of different students so that the difficulties experienced by students can be minimized. Next, abstract mathematical concepts also cause students difficulty understanding mathematical concepts, giving rise to anxiety when learning mathematics.

As explained previously, different methods and approaches are needed to overcome students' learning difficulties, especially understanding abstract concepts. One approach that can be used is using technology-assisted learning. This is because technological developments provide opportunities to change the paradigm of mathematics learning through various innovative tools and applications. Technology can also make it easier for students to understand concepts that are considered complicated or abstract. As stated, technology is seen as a tool that can help students understand abstract objects in mathematics. Previous research also found that technology through digital learning can potentially improve student learning outcomes.

One technology that can be used in mathematics learning is the GeoGebra Applet. GeoGebra Applet is one of Geogebra's features that allows visualization of mathematical objects and direct exploration of concepts. GeoGebra Applet can help overcome difficulties experienced by students by providing interactive tools that allow students to be actively involved in the learning process. By presenting mathematical concepts visually, GeoGebra Applet helps students to build intuition and a deeper understanding of learning material. Combining technology with the mathematics curriculum allows GeoGebra Applets to be integrated into learning activities, allowing students to conceptualize mathematical abstractions more concretely and enjoyably.

Various studies have examined the development and implementation of the GeoGebra Applet in mathematics learning, such as research conducted (Jiménez-Sánchez, 2022)

regarding applets for teaching financial mathematics, which obtained results that applets helped students build their study conducted by (Radović, Radojičić, Veljković, & Marić, 2020) tested the effect of GeoGebra Applets on mathematics learning using an interactive mathematics textbook. The research showed that mathematics textbooks using GeoGebra Applets can increase students' knowledge and retention. Furthermore, other research also found that using geometric representations in the GeoGebra Applet increased students' understanding of more complex mathematical concepts.

Based on these studies, the GeoGebra Applet provides a suitable platform for honing students' skills, allowing them to develop their mathematical skills while gaining a deeper and deeper understanding of concepts, making it suitable for use in learning activities. However, it is necessary to deepen previous research that has been carried out regarding the GeoGebra Applet. This is because, to improve mathematics learning through the development and integration of the GeoGebra Applet, it is necessary to know the research potential that can be carried out. Therefore, exploring previous research related to the Development and Integration of GeoGebra Applets in Mathematics Learning is necessary. This article will explore in more detail the development process of the GeoGebra Applet and its integration strategies in mathematics learning. By highlighting the positive potential of the GeoGebra Applet form that can be developed and the capabilities, materials, and learning applied, this article aims to encourage wider application of mathematical technology, especially the GeoGebra Applet, among educators and students.

The novelty of this research lies in the use of GeoGebra Applets integrated with other applications, which has not been widely researched before, especially in the context of education in Indonesia. By exploring the use of GeoGebra Applets for mathematics topics beyond geometry, this research opens new avenues to enrich existing methods of teaching and learning mathematics. In addition, this research proposes an innovative approach to develop various mathematical abilities through GeoGebra Applets, which can improve students' critical thinking, spatial, creative and reasoning skills.

The significance of this research for education in Indonesia is substantial, given that mathematics is often perceived as a challenging subject. The implementation of GeoGebra Applets, which has been proven to improve students' mathematical understanding and skills, provides new tools for teachers to improve the quality of teaching. This research also demonstrates the potential of GeoGebra Applets in supporting independent, hands-on, and innovative learning, which is aligned with educational efforts in Indonesia to advance 21st century education and develop students' mathematical skills.

Method

The method used in this research is a Systematic Literature Review or SLR. SLR aims to carry out a comprehensive synthesis of research results referring to certain questions through systematic, clear steps, and there can be a replication process at each stage. The topic discussed in this research is the Development and Integration of GeoGebra Applets in Mathematics Learning, so the keywords geogebra, applet, and mathematics are used in identifying, evaluating, and extracting the essence of research appropriate to the topic discussed.

The procedure used in this SLR research was adopted from the stages of Francis & Baldesari (2006). These stages include formulating research questions, applying inclusion criteria, looking for written work relevant to GeoGebra Applet Development and Integration

in Mathematics Learning, selecting the written work found, analyzing, and reporting the results.

The first stage carried out was formulating research questions. The formulation of questions in this research includes the following.

1. What is the shape of the GeoGebra Applets developed in previous research?
2. What material was discussed in GeoGebra Applets in mathematics learning in previous research?
3. What mathematical abilities have been facilitated through mathematics learning using GeoGebra Applets?
4. How is mathematics learning implemented using GeoGebra Applets, which have been studied in previous research?

Next, the stage is to apply the inclusion criteria. The inclusion criteria used in this research were articles discussing the development of GeoGebra Applets in mathematics learning; articles discussing the integration of GeoGebra Applets in mathematics learning; articles about mathematical material used in the GeoGebra Applet; articles about the capabilities addressed through the use of GeoGebra Applets; articles originating from journals, proceedings and books indexed by Scopus; and articles published between 2013 and 2023. Inclusion criteria were used as boundaries to filter the articles analyzed.

The next stage is to look for research relevant to the topic of the Development and Integration of GeoGebra Applets in Mathematics Learning. At this stage, research articles are collected through searches on the Scopus website. The keywords used to find research articles are GeoGebra Applet and mathematics. At this stage, 39 articles that matched the keywords used were found.

The fourth stage is selecting the research articles found. The activity of selecting research articles is carried out based on the inclusion criteria created. Twenty-seven articles met the inclusion criteria. Research articles that meet the inclusion criteria are then subjected to the analysis stage.

The final stage is carrying out analysis and reporting the results. At this stage, knowledge is obtained by analyzing articles that meet the inclusion criteria. The findings are synthesized to provide insights into the development and integration of GeoGebra Applets in mathematics learning. The research steps taken can be seen from the following flowchart image.

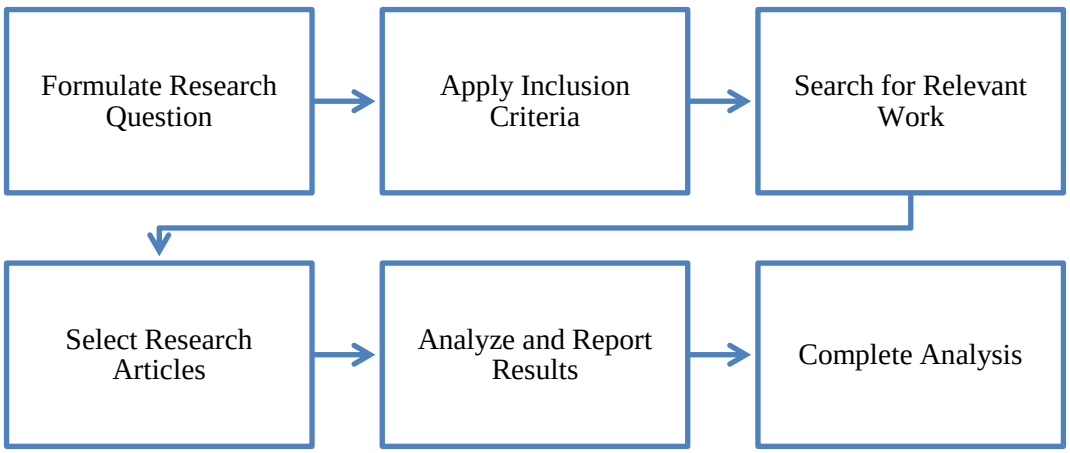

Figure 1. Flowchart of Research Steps Undertaken

Results and Discussion

Authors collected 27 articles, which were analyzed using the Vos Viewer application to see an overview of the GeoGebra Applets research that had been carried out. Articles are processed using the binary counting method, with the minimum number of occurrences of a term set to 6 and the number of terms to be selected set to 14. From these choices, 14 terms appear research, applet, tool, paper, geogebra applet, teaching, teacher, learning, study, mathematics, geogebra, student, use, and development.

Vos Viewer results show that 2 clusters were formed. The first cluster is marked in red and contains mathematics, geogebra, student, use, applet, tool, paper, and teaching. The second cluster marked in green consists of the words research, geogebra applet, teacher, learning, study, and development. This means that cluster 1 is more related to mathematical abilities through the use of the GeoGebra Applet, while cluster 2 is related to development research to develop the GeoGebra Applet. The Network Visualization Vos Viewer display can be seen in Figure 2 below.

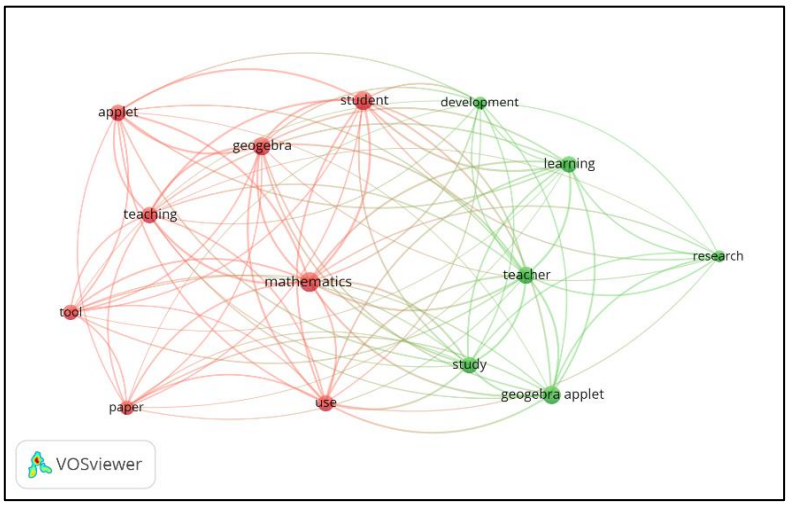

Figure 2. Network Visualization Vos Viewer display

We can also see the Network Visualization Vos Viewer display and the Density Visualization display. The Density Visualization Display can be seen in Figure 3 below.

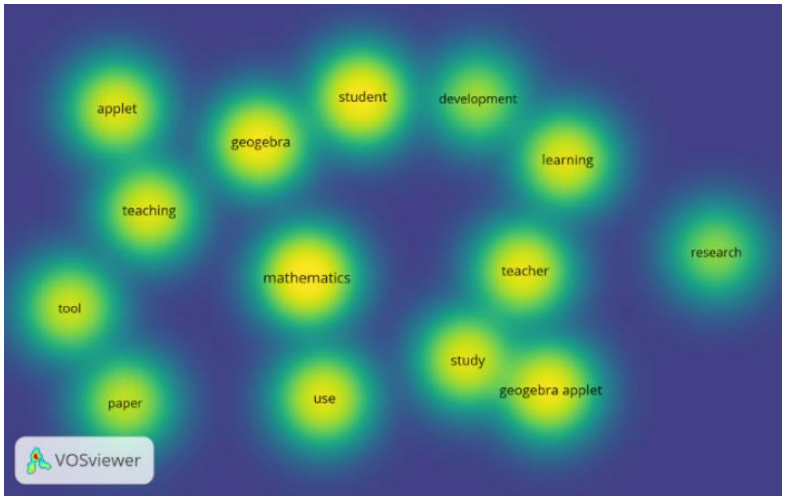

Figure 3. Vos Viewer Density Visualization Display

Topics with lighter colors in Figure 3 indicate that these topics have been researched more than other topics. Based on Figure 3, this means that most topics have relatively the same number of appearances. Only the research and development section has a greener color than other topics. This shows that development research related to the GeoGebra Applet can be researched further.

Next, the research articles that have been collected are reviewed again to answer the research questions. The research questions answered are: 1) What is the shape of the GeoGebra Applets that have been developed in previous research?; 2) What material was discussed in GeoGebra Applets in mathematics learning in previous research?; 3) What mathematical abilities have been facilitated through mathematics learning using GeoGebra Applets ?; 4) How is mathematics learning implemented using GeoGebra Applets which has been studied in previous research?. The discussion of each question is explained in the following description.

GeoGebra Applets Forms That Have Been Developed in Previous Research

GeoGebra Applets are part of the GeoGebra software, which is interactive, in the form of an output file with the extension. ggb, which can be downloaded, installed, or used either on a personal computer, android device, or via the web (Nisiyatussani, Ayuningtyas, Fathurrohman, & Anriani, 2018). Because of its flexibility, GeoGebra Applets can be given to students in the application form and embedded in ebooks, the web, etc. Therefore, the first research question is related to the shape of the GeoGebra Applets developed in previous research. There are 22 articles to answer this research question. The following pie chart depicts the distribution of articles for the first research problem.

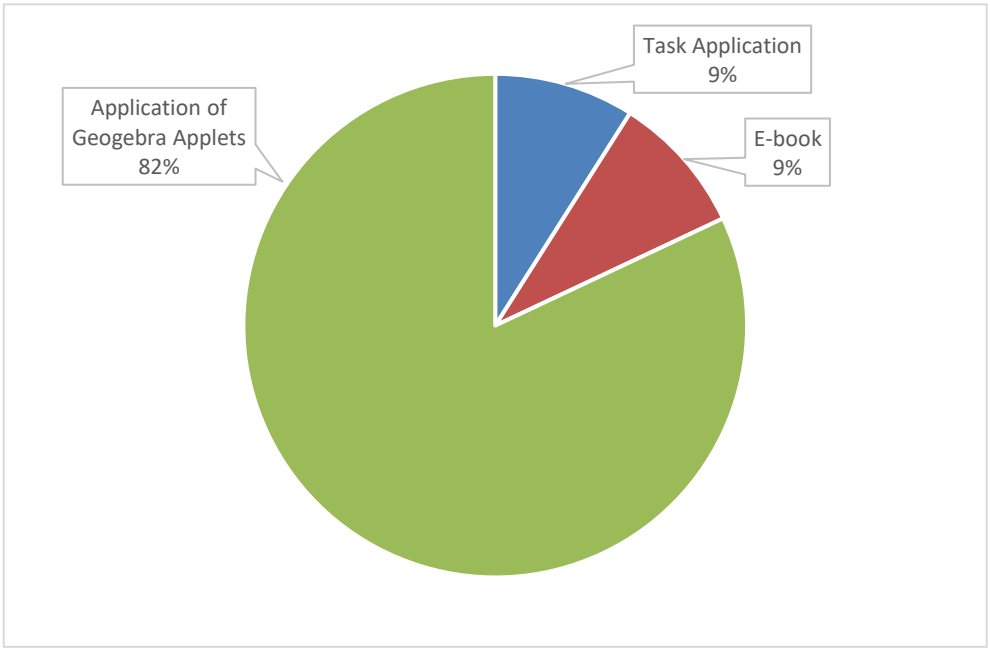

Figure 4. Forms of the Geogebra Applets Developed

Based on the pie chart, it is evident that the GeoGebra Applets developed take three forms: GeoGebra Applet applications, ebooks, and task applications. The GeoGebra Applet applications are the most widely utilized, with 18 articles contributing to their development. This preference for GeoGebra Applet applications is attributed to their user-friendly nature, as noted by (Urgena & Lapinid, 2017; Funes & Kari, 2019; Jiménez-Sánchez, 2022).

Additionally, these applications are accessible free of charge to anyone, anywhere, and anytime, as emphasized by (Urgena & Lapinid, 2017; Mavani, Mavani, & Schäfer, 2018; Funes & Kari, 2019; Olivares-Funes & Valero-Kari, 2023).

Ebooks and task applications share an equal percentage, each comprising 9%. The developed ebooks include GeoGebra Applets and incorporate open courseware, YouTube videos, Wikipedia articles, Slideshare presentations, and other relevant web content, as outlined by (Kushwaha, Singhal, & Biswas, 2020). The hope is that these ebooks meet pedagogical needs and address didactic requirements for learners, allowing for high interactivity and feedback during the learning process, as highlighted by (Radović et al., 2020).

Task applications featuring GeoGebra Applets, namely automath and digital task applications, have been developed twice. The developed automath application combines the strengths of GeoGebra Applets with STACK (Pinkernell, Diego-Mantecón, Lavicza, & Sangwin, 2023). The dynamic, interactive nature of GeoGebra Applets, widely used in secondary school mathematics education, is complemented by STACK's ability to provide randomized tasks, adaptive feedback, and greater use in university-level mathematics education. The next task application form is the digital task, created by adopting the theory of didactic situations (Tamba, 2022).

Material Discussed in GeoGebra Applets in Mathematics Learning in Previous Research

Mathematics is often perceived as a challenging and sometimes abstract subject by most learners. Students frequently encounter difficulties in understanding complex and intricate mathematical concepts. Therefore, using instructional media becomes crucial in assisting learners in comprehending the material or overcoming obstacles they may face while learning mathematics. Instructional media, such as interactive applications, visual diagrams, or educational games, can provide a more dynamic and engaging approach, making mathematical concepts easier to understand and remember. By designing instructional media, teachers can also provide learners with opportunities to reinforce their understanding of mathematics through enjoyable and effective exploratory activities.

One instructional media that helps learners understand the material and captivates their interest is the GeoGebra Applet (Putra, Hermita, Tamimi, Noviana, & Jismulatif, 2022). Furthermore, GeoGebra Applets can be designed as exploratory, interactive, and dynamic learning resources (Dockendorff & Solar, 2018; Urgena & Lapinid, 2017; Martín-Caraballo & Tenorio-Villalón, 2015 Pinkernell et al., 2023; Radović et al., 2020; Jahodová, Krček, & Morávková, 2019; Dimitrov & Slavov, 2018; Nisiyatussani et al., 2018). The exploratory nature of GeoGebra Applets means that by using GeoGebra, learners can conduct in-depth visual explorations of mathematical concepts. The interactive and dynamic features of GeoGebra Applets allow learners to manipulate mathematical objects directly, enabling them to observe the impacts of those changes, connect theory with mathematical applications, and draw conclusions from the learned material.

The second research question pertains to the content covered in previous studies in GeoGebra Applets in mathematics education. To answer this research question, 21 articles were referenced. The distribution of articles for the second research question is depicted in the following pie chart.

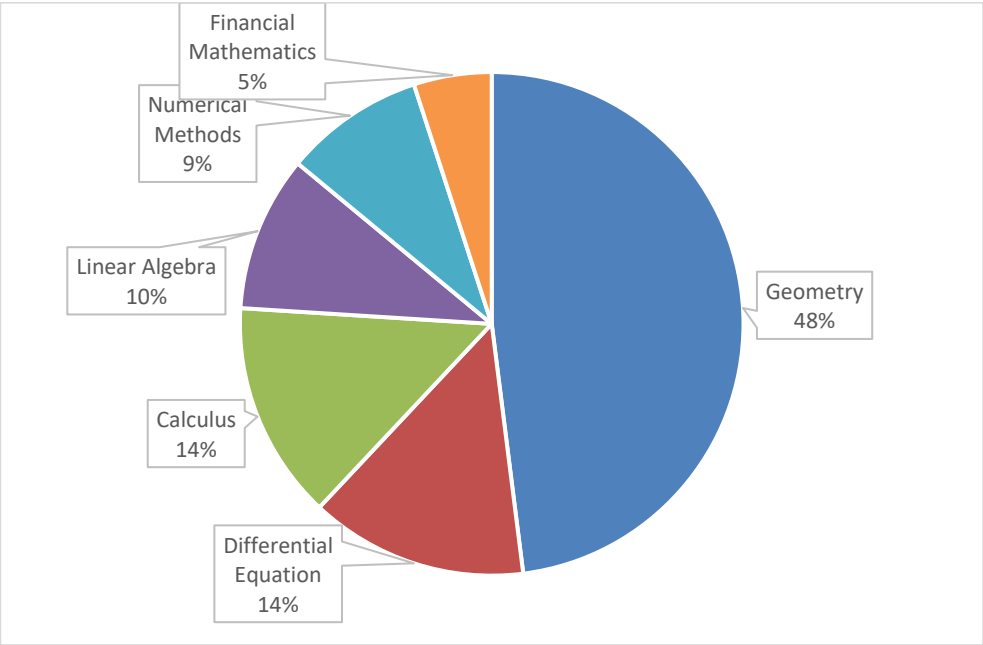

Figure 5. Material Discussed in Geogebra Applets that Have Been Developed

Based on the above diagram, it is evident that geometry is the most extensively covered subject using GeoGebra Applets. This is attributed to the challenges in learning GeoGebra material concerning visualization and construction, which can be overcome by utilizing GeoGebra Applets. Geogebra applets, as part of Geogebra, can be designed to form points, lines, all curves, and other mathematical objects, making it a preferred application for aiding in the visualization of representations of mathematical objects (Japa, Suarjana, & Widiana, 2017).

GeoGebra Applets are not limited to teaching geometry. This is because GeoGebra Applets, as part of GeoGebra, encompass various features in graphics, algebra, tables, geometry, and calculus. Therefore, they can be used not only as visualization tools but also for exploring and modeling mathematics (Mulyadi et al., 2023). Figure 5 above shows that GeoGebra Applets have been employed to teach subjects beyond geometry, such as linear algebra, numerical methods, financial mathematics, calculus, and differential equations. The relatively small percentage of usage indicates that the utilization of GeoGebra in these subjects is open to further exploration. Additionally, other matters that have not been examined in previous research present opportunities for investigation and could be the focus of new research endeavors.

Material Mathematical Abilities That Have Been Facilitated Through Mathematics Learning Using GeoGebra Applet

The third research question is related to what mathematical abilities have been facilitated through mathematics learning using the GeoGebra Applet. There are 15 articles referenced to answer this research question. The distribution of articles for the third research problem is depicted in the following pie chart.

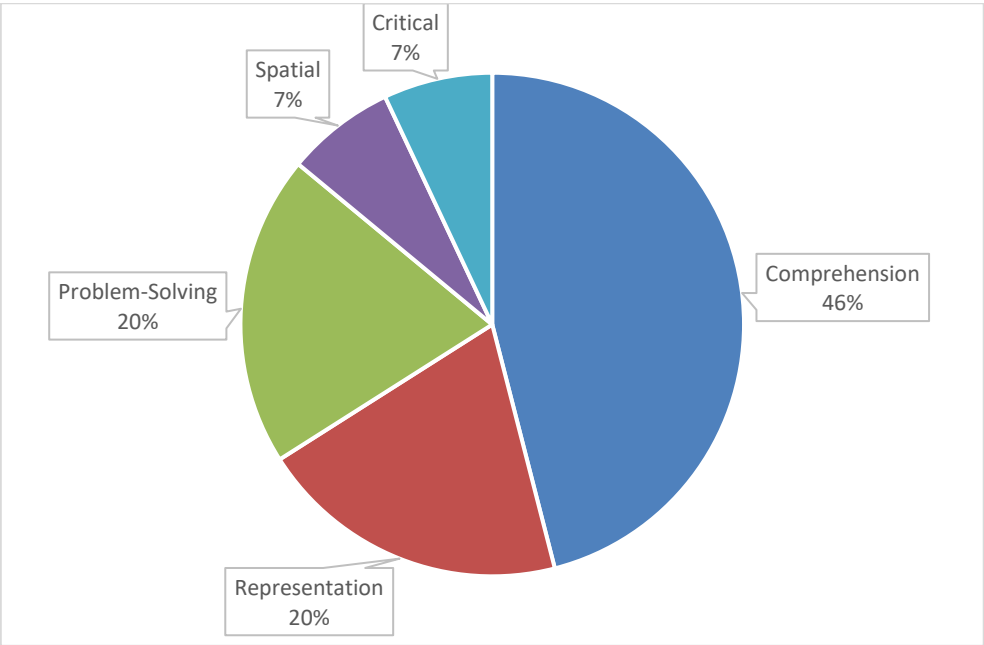

Figure 6. Abilities that Facilitated through Mathematics Learning using GeoGebra Applets

In Figure 6, it is evident that the most extensively studied capability is the ability to understand. This implies that the development of GeoGebra applets is largely aimed at improving comprehension or learning outcomes (Olivares, Pastén, & Rodríguez, 2023; Putra, Hermita, Alim, & Witri, 2021; Segal, Stupel, & Oxman, 2016; Havelková, 2013). This is because GeoGebra Applets assist learners in understanding graphic concepts in more detail through direct interaction with images, supported by more varied and engaging displays (Ardiyanto, 'Adna, & Chasanah, 2022).

Representation and problem-solving abilities share an equal percentage in their examination of GeoGebra applets. Representation ability is one of the fundamental skills that connects abstract ideas with logical thinking to understand mathematics (Widakdo, 2017). Problem-solving ability is a complex process that involves identifying the problem and its main features, using imagination based on experience to understand and detail the problem, actively engaging in problem-solving, analyzing various possible solutions, concluding and making decisions to choose the most appropriate or effective solution (Kaya, Izgiol, & Kesan, 2014). GeoGebra Applets can support representation and problem-solving abilities because GeoGebra helps visualize mathematical concepts, where visualization is a form of representation, and visualization is also essential in problem-solving. This aligns with the statement (Nurfadilah & Suhendar, 2018) that without good mathematical visualization, learners will find it difficult to solve mathematical problems.

Critical and spatial abilities are skills that share an equal percentage in their examination within GeoGebra Applets, namely 9%. The National Council for Excellence in Critical Thinking (NCECT) defines critical thinking as the disciplined intellectual process actively and skillfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information gathered from or generated by observation, experience, reflection, reasoning, or communication as a guide to beliefs and actions (Changwong, Sukkamart, & Sisan, 2018). Meanwhile, spatial ability is the student's ability to deeply understand the relationship between objects and space, which helps enhance learners' understanding of mathematical concepts (Sopyan & Supiarmo, 2022). The integrated use of GeoGebra Applets inappropriate learning, such as Galileo experiments, can encourage students to question and

reconsider what they know and interpret newly discovered concepts, thereby fostering learners' critical thinking abilities (Campuzano, Matthews, & Adams, 2018). In addition to critical thinking abilities, GeoGebra Applets help learners improve spatial abilities (Bímová & Pirklová, 2018).

Implementation of Mathematics Learning Using GeoGebra Applets, which have been studied in previous research

The fourth research question is related to how to implement mathematics learning using GeoGebra Applets, which has been studied in previous research. There are 18 articles referenced to answer this research question. The following pie chart depicts the distribution of articles for the fourth research problem.

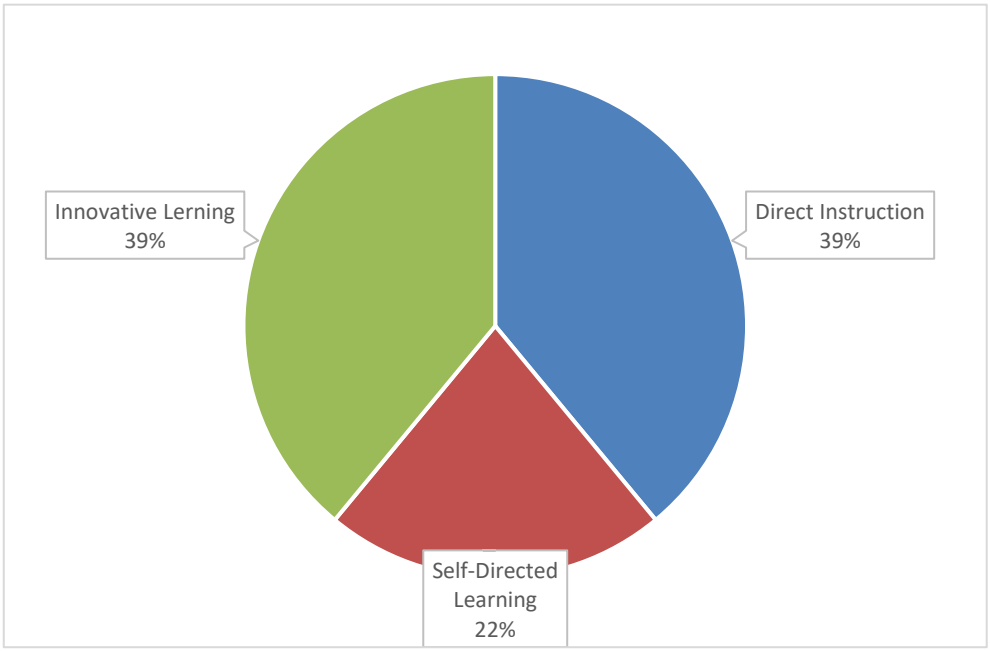

Figure 7. Implementation of Mathematics Learning using GeoGebra Applets

Figure 7 shows that the integration of GeoGebra Applets in mathematics education is carried out through self-directed learning both inside and outside the classroom, direct instruction, and innovative learning. Innovative and direct instruction forms have an equal frequency of usage. Innovative learning takes the form of constructivist learning, TPCK, Galileo experiment learning, exploratory learning, and collaborative learning (Urgena & Lapinid, 2017; Mavani et al., 2018; Dockendorff & Solar, 2018; Olivares-Funes & Valero-Kari, 2023). The use of GeoGebra Applets in various instructional methods is essentially employed to capture the interest of learners and enhance their engagement in the learning process (Triantafyllou & Timcenko, 2013; Urgena & Lapinid, 2017; Putra et al., 2021; Olivares-Funes & Valero-Kari, 2023).

Based on the research findings, further research related to developing and integrating GeoGebra applets in mathematics education is still open. Regarding the forms of GeoGebra Applets, based on the obtained research results, GeoGebra Applets as standalone applications are the most developed or used in mathematics education. However, there is still limited research on GeoGebra Applets integrated with other applications. Yet, GeoGebra Applets can optimize other applications, such as ebooks and task applications.

Therefore, the development and utilization of GeoGebra applets integrated with other applications have the potential for further exploration.

In terms of content, geometry is a subject that has been extensively studied in its use with GeoGebra Applets. However, GeoGebra Applets can be applied not only to geometry but also to other mathematical topics. This is because GeoGebra Applets, as part of Geogebra, encompass various features in graphics, algebra, tables, geometry, and calculus. Hence, they can be used not only as visualization tools but also for exploring and modeling mathematics. Therefore, the development and use of GeoGebra Applets for subjects other than geometry have the potential for further research.

Examining the facilitated abilities using GeoGebra Applets, understanding ability is the most frequently studied in previous research. However, many other abilities have been either minimally or not at all explored through learning using GeoGebra Applets, such as critical thinking, spatial ability, creative thinking, reasoning ability, etc. Therefore, the opportunity to research using GeoGebra Applets to facilitate various mathematical abilities is still substantial.

Regarding the instructional methods used, Geogebra Applets can be integrated into various innovative learning approaches, such as constructivist learning, TPCK, Galileo experiment learning, exploratory learning, and collaborative learning. The prevalence of innovative learning methods not extensively explored in previous research opens up opportunities for studying the integration of GeoGebra Applets in innovative learning.

Conclusion

Analysis of 27 research articles on GeoGebra Applets with the Vos Viewer revealed a research trend focused on developing maths skills and improving learning tools, with 14 key terms appearing frequently such as 'GeoGebra', 'applets' and 'learning'. The Network Visualisation shows two main clusters, the first relating to mathematical skill building through GeoGebra Applets and the second to research and development of the applets themselves. GeoGebra Applets have been developed in various forms and the majority are used in geometry, but there is potential for further exploration in other topics. These applets were shown to support the enhancement of understanding, representation, problem solving, as well as critical and spatial thinking in mathematics education. Based on these findings, it is recommended that future research leads to the integration of GeoGebra Applets with other applications, the development of content beyond geometry, and the enhancement of various mathematical abilities, as well as the application of GeoGebra Applets in various innovative learning methods.

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