INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN PROGRESSIVE EDUCATION & DEVELOPMENT

OPEN ACCESS JOURNAL

Vol 12, Issue 3, (2023) E-ISSN: 2226-6348

A Systematic Review of GeoGebra in Mathematics Education

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To Link this Article: http://dx.doi.org/10.6007/IJARPED/v12-i3/19133 DOI:10.6007/IJARPED/v12-i3/19133

Published Online: 16 September, 2023

Abstract

GeoGebra is a dynamic mathematics software that serves as a valuable tool for mathematics teachers, supporting the teaching of abstract concepts in measurement and geometry, relationships and algebra, as well as statistics and probability. Through its interactive features, GeoGebra enables teachers to create visual representations, conduct measurements, and explore geometric properties, fostering a deeper understanding of geometric concepts. This study takes a systematic approach to evaluating users' perspectives and perceptions of GeoGebra, and the implementation of GeoGebra in mathematics education. For a more accurate comparison of sources, this study employs a thorough analysis and synthesis of 15 publications published between 2018 and 2023, including full-text articles and peer-reviewed journal articles from Google Scholar, Scopus, and the Web of Science. The results of this study show that the quantitative method is the most widely used method for exploring the perspective and perception of users towards GeoGebra and the implementation of GeoGebra in mathematics education. The findings of this study demonstrate that most users have a favourable opinion of GeoGebra and that it has a beneficial influence on learning outcomes. In summary, GeoGebra is an effective tool for enhancing user skills like problem-solving and visualisation, as well as for facilitating teaching and learning.

Keywords: GeoGebra, Mathematics Education, Users' Perspectives, Implementation, Systematic Approach

Introduction

Current developments in the Industrial Revolution 4.0 have transformed and advanced several industries, including education. Education 4.0 refers to the current state of education (Hussin, 2018). According to Khalil et al (2020), this term describes student-centred learning, a focus on 21st century skills, lifelong learning, and the incorporation of technology in the classroom. Teachers and students now have many chances to enhance the quality of education and increase access thanks to the introduction of numerous new technologies in today's educational environment. They have opportunity to connect and access new knowledge around the world by using technology. Hence, it can be a reason to use the technology in mathematics education.

The use of technology in mathematics education is crucial. This is due to the need to produce individuals who are highly skilled and able to face the challenges of the 21st century. Furthermore, it is simpler for teachers to communicate learning content when technology is used in mathematics education (Perienen, 2019), and it also enhances their teaching effectiveness (Rafi & Sabrina, 2019). When educational software is employed in the teaching and learning process, student achievement and motivation in mathematics can also be increased (Saipudin et al., 2023; Rusli et al., 2020; Abdullah et al., 2020). Among the dynamic software that can be used by mathematics teachers is GeoGebra.

GeoGebra software is one of the educational software provided to teachers in mathematics subjects. This software is among the most important ones in Malaysia's high school mathematics curriculum (Za'ba et al., 2020). Other than Malaysia, it also is widely use in the many countries such as Indonesia (Diva et al., 2023), South Africa (Manganyana et al., 2020), Austria (Weinhandl et al., 2020), and Turkey (Saralar-Aras, 2022). Its use all over the world is due to the fact that this software is free without requiring a licence and is easy to use compared to other mathematics education software.

Moreover, the teaching of abstract mathematics can be made simpler for mathematics teachers by using this software (KPM, 2016). This is because, in accordance with the combination of the names Geometry and Algebra, this software is a combination of geometry, algebra, spreadsheets, graphics, statistics, and calculus on one platform (Belgheis & Kamalludeen, 2018). This shows that this software has multiple functions and can be used in various fields of mathematics. This area of abstract mathematics calls for a strong capacity for imagination and logical thought. Hence, it will be easier for teachers to efficiently teach mathematics in the classroom with the help of this software (Belgheis & Kamalludeen, 2018).

Despite the fact that GeoGebra is widely used, it is still vital to understand how users in the field of mathematics education perceive and employ it during the teaching and learning process. User perceptions may affect how GeoGebra is used in the classroom (Bedada & Machada, 2023). GeoGebra may be used less effectively if users' perceptions and willingness to use it are not taken into account. Therefore, understanding how users view GeoGebra can assist users in determining the demands for its adoption and enhance the quality of mathematics instruction as technology advances. The user perceptions of GeoGebra and its use in mathematics instruction across various levels of educational institutions have been the subject of numerous empirical research studies (Hidayat & Hamzah, 2022; Ng & Rosli, 2023; Puotier et al., 2023).

Considering the wealth of studies, systematic reviews analysing GeoGebra users' viewpoints and perceptions of the software's application in mathematics education are scarce. In order to better understand user perspectives and perceptions as well as the application of GeoGebra in mathematics education, this review will integrate previous research findings in these areas. First, researcher characterises GeoGebra as a free digital-based mathematics learning tool (Hia & Nainggolan, 2023) that enables students to master abstract mathematical subjects like geometry and algebra (Hamzah & Hidayat, 2022). In order to support their use in mathematics education, GeoGebra refers to a dynamic mathematical programme that may be used by mathematics teachers and students both online and offline through the use of computers, smartphones, and tablets.

This systematic review study's objective was to critically emphasise the users' perspective and the use of GeoGebra in mathematics education in the chosen literature. The following inquiries will be discussed in this study: 1) What are users' perspectives and

perceptions towards GeoGebra? and 2) How can GeoGebra be implemented in mathematics education?

GeoGebra in Education

GeoGebra is a dynamic mathematical software that was introduced by Markus Hohenwarter in 2002 as a project in his master's and doctoral studies in philosophy (Condori & Fernandez, 2023). The name GeoGebra is a combination of two mathematical fields, namely Geometry and Algebra. Accordingly, GeoGebra can be used to explore mathematical topics such as geometry (Linda Vu, 2018; Silfanus, 2020; Kashiem, 2021; Mui Kim, 2020; Adelabu, 2019), distance (Ljajko, 2016), linear equations (Joshi, 2020), functions (Sharifah, 2016; Zulnaidi, 2019; Mushipe, 2019; Zulnaidi, 2017; Kohen, 2019; Francisco, 2019), trigonometry (Mosese, 2021), analytic geometry (Suweken, 2017; Khalil, 2018), Isometry (Gutierrez, 2021), functional graph 2 (Halim, 2020), and triangle (Nurhayati, 2020). This means that GeoGebra can be used as a support tool in learning mathematics so that students can understand and master mathematical concepts well.

According to a study by Manganyana et al. (2020), GeoGebra is a very successful pedagogical tool for teaching geometry in South African deep rural schools. For students who reside in underdeveloped, rural locations without access to the Internet, this option does not exist. GeoGebra helps improve geometry instruction and learning in isolated schools because it can be used without an Internet connection. This is corroborated by a study conducted by Bayaga et al. (2019), who discovered that GeoGebra use had a statistically significant impact on students' ability to successfully solve problems using circle geometry theorems.

In addition, the use of GeoGebra is seen as an alternative to new teaching methods. This can be proven through a pre- and post-test study by Owusu et al. (2023), who found that the achievement of university students in Ghana is better compared to the conventional method. The study of Rahman et al. (2023) also proved that the use of GeoGebra can improve high-order thinking skills (HOTS) in secondary school students when compared to conventional teaching. This is also supported by the study of Ishartono et al. (2022), who showed that GeoGebra-integrated flipped learning is more effective in raising students' levels of independent study in online mathematics learning compared to traditional flipped learning and conventional teaching approaches. This shows that the use of GeoGebra in the classroom can change the conventional teaching practises often used by mathematics teachers.

As is known, mathematics requires high logical skills to enable students to solve mathematical problems easily (KPM, 2019). The use of technology can help students visualise mathematical concepts and improve their mathematical learning experience (Diva et al., 2023). Through the use of GeoGebra, it gives students the opportunity to improve their visualisation and imagination skills in mastering abstract mathematical concepts. This allows students to think critically, creatively, and innovatively. This coincides with the statement of Kim and Ali (2020) that this software encourages students to solve mathematical problems and produce assignments more creatively and innovatively.

In conclusion, GeoGebra is an educational resource that facilitates the teaching and learning process of mathematics. The use of GeoGebra in the classroom has many advantages for both teachers and students. Based on previous studies, this software can improve soft skills, motivation, meaningful experiences, and positive attitudes among users in mathematics education. The use of GeoGebra, which is a student-centred learning method, can develop the professionalism of a teacher and improve the quality of mathematics

education. Its use all over the world also shows that this software is suitable for use everywhere and is beneficial to users.

Method

A systematic literature review (SLR) was carried out to determine the users' perspective and the utilisation of GeoGebra in mathematics education. According to Hamzah and Hidayat (2022), SLR is a study that necessitates the development of precise research questions by employing systematic and explicit procedures for locating, choosing, assessing, collecting, and analysing data from prior studies. It thoroughly and comprehensively comprehends the existing information by analysing pertinent studies and identifying gaps that need to be investigated. According to Zakaria (2023), there are five phases in a systematic review, as shown in Figure 1 below.

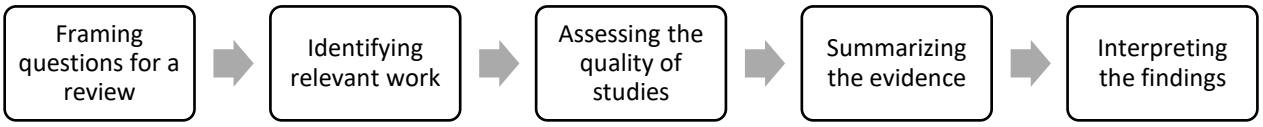

Figure 1: Phase in Systematic review

Phase 1 : Framing Questions for A Review

For the first phase, the review questions for this study were created by looking up pertinent issues and problems discussed in earlier research. The researcher started by looking for earlier systematic reviews that addressed the implementation of GeoGebra in mathematics instruction and its outcomes. However, the researcher was unable to find any papers that addressed this issue. Therefore, the following inquiries were sought to be addressed by this study: 1. What are users' perspectives and perceptions towards GeoGebra? and 2) How can GeoGebra be implemented in mathematics education?

Phase 2 : Identifying Relevant Work

Gathering pertinent studies during the preliminary search and determining their acceptability based on inclusion and exclusion criteria were the key steps engaged in the second phase. Peer-reviewed materials and full-text publications were the only search criteria used for this investigation. Over the course of a month, the researcher used a variety of keywords, including "GeoGebra in mathematics education," "implementation of GeoGebra in mathematics education," "students perspectives and perceptions towards GeoGebra," and "teachers perspectives and perceptions towards GeoGebra," to conduct an initial search on Google Scholar and Web of Science. During the preliminary search, the title and abstract were the researcher's two key considerations.

Phase 3 : Assessing The Quality of Studies

In the third phase, a study selection approach was used to find the pertinent papers that should be included in the review in order to maintain its quality. Potential primary studies were identified using inclusion and exclusion criteria, and those that met the criteria were preferred for inclusion in this analysis. As a result, the chosen studies had to satisfy the following prerequisites in Table 1 below.

Table1
Article Acceptance and Rejection Criteria

Criteria	Description
Inclusion	1. The articles were published from 2018 – 2023. 2. The articles in Malay and English languages. 3. The articles are available electronically. 4. Used research methodology. 5. Studies in the field of GeoGebra and mathematics education.
Exclusion	1. The articles are not published in 2018 – 2023. 2. The related articles are not in Malay and English languages. 3. Studies are not in the field of GeoGebra and mathematics education.

Phase 4 : Summarizing The Evidence

Next, for the fourth phase, Google Scholar and the Web of Science were used as the literature databases in this review to find pertinent studies. Several key terms, including "GeoGebra in mathematics education," "implementation of GeoGebra in mathematics education," "students perspectives and perceptions towards GeoGebra," and "teachers perspectives and perceptions towards GeoGebra," were used by the researchers during their search. Through the use of both databases, 305 studies published between 2018 and 2023 were found, with 185 coming from Google Scholar and 120 from the Web of Science. 152 results remained after the results were filtered to remove non-Malay and non-English texts as well as non-journal sources. 50 duplicate results were then removed after 104 results were dropped because they failed to provide full-text articles and 71 did not satisfy the inclusion criterion. The researchers ultimately discovered 15 publications, which were further examined using the entire text. The search procedure is summarised in the PRISMA flow chart in Figure 2. Lastly, the key findings will be summarized in Table 2. The content analysis method was used to analyse the findings.

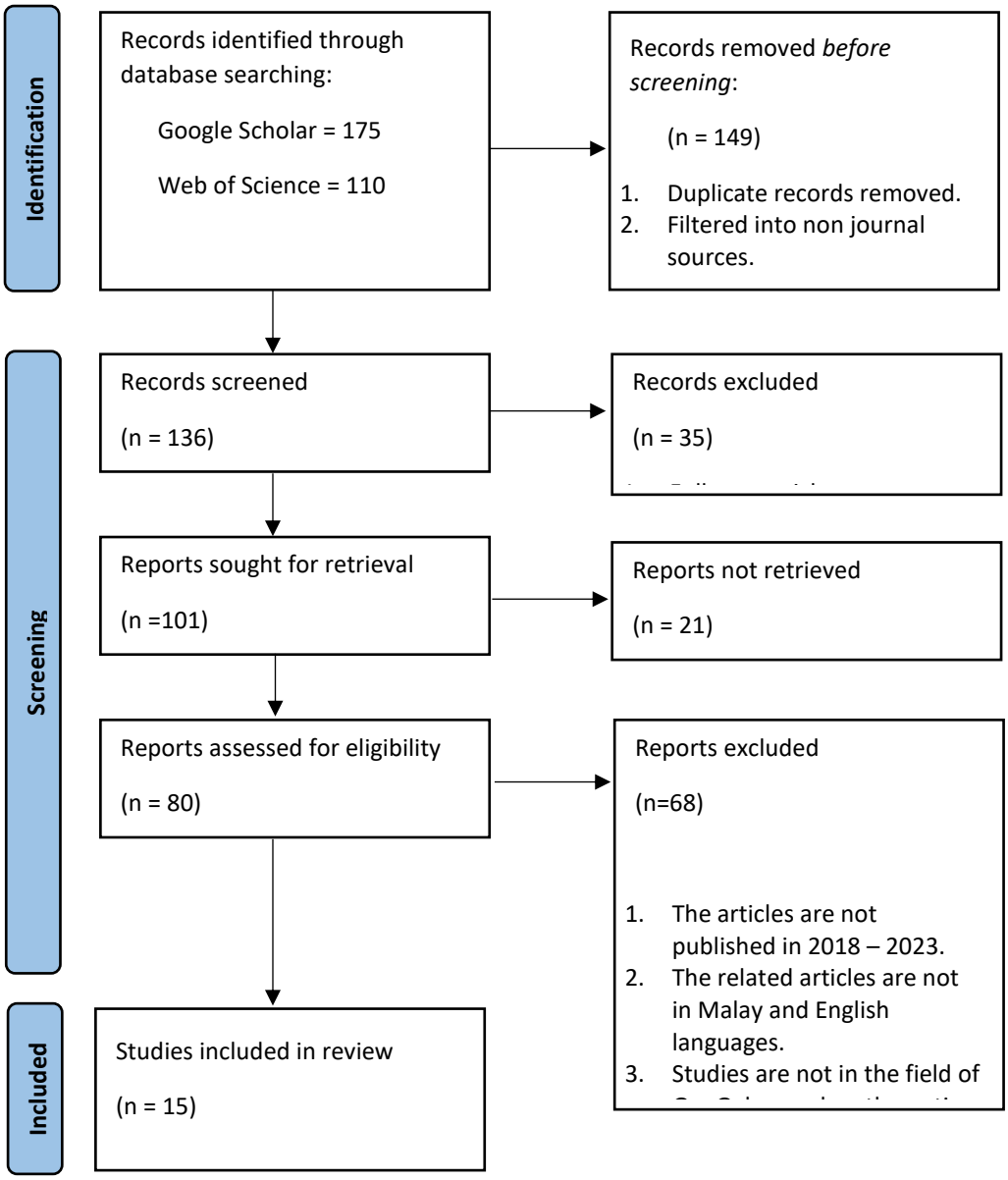

Figure 2: PRISMA flow chart

Phase 5: Interpreting The Findings

The researchers utilized content analysis as a method to study the outcomes. The researchers sorted previous studies into three categories based on the methodologies; quantitative, qualitative, and mixed methods to identify patterns. The researchers conducted a systematic assessment of educational studies published between 2018 and 2023, with a focus on users' perspectives and perceptions regarding GeoGebra and its implementation in mathematics education. Initially, 285 studies were identified, but only 15 empirical studies met the inclusion criteria and were used to address the study's objectives. Table 3 presents the analysis technique applied to the publications from 2018 to 2023. According to the table, the earlier research predominantly employed the quantitative approach, followed by the qualitative and mixed methods.

Table 2
Numbers of study based on methods

Methods	Google Scholar	ERIC
Quantitative	4	2
Qualitative	3	2
Mixed method	3	1

Results

There are 15 articles that have been selected and reviewed to answer two research questions after implementing the review process using the PRISMA (2020) protocol. The two questions are: 1) What are users' perspective and perception towards GeoGebra? and 2) How can GeoGebra implemented in mathematics education? Table 3 is a summary of the reviewed studies.

Table 3
Summary of Reviewed Studies

No	Authors	Discussions
1.	Owusu et al. (2023)	In regard to using GeoGebra software in the educational process, students have favourable attitudes and perspectives. The pupils did better when learning about polar coordinates using GeoGebra as opposed to the traditional method.
2.	Condori & Fernandez (2023)	Due to limited access to technology and inadequate training, mathematics teachers found it challenging to integrate GeoGebra into mathematics education.
3.	Suratno, & Waliyanti (2023)	Student problem-solving skills are considerably improved when GeoGebra is used in problem-based learning.
4.	Saralar-Aras (2022)	GeoGebra can be utilised to provide visual representations, facilitate student learning, raise engagement, lessen burden, and save time, according to middle school mathematics teachers. They encountered issues with lesson planning, social context, time management, and classroom organisation.
5.	Ishartono et al. (2022)	In comparison to other traditional flipped learning and conventional teaching approaches, GeoGebra-integrated flipped learning is more effective in raising students' levels of independent study in online mathematics learning.
6.	Handayani et al. (2022)	Students' motivation and problem-solving skills increased more after learning through GeoGebra-assisted Creative Problem Solving (CPS) than when using conventional teaching strategies.
7.	Bedada & Machaba (2022)	The usage of GeoGebra for studying differential calculus was seen favourably by the students, and

		they were happy with the choices made for the study's GeoGebra lesson-oriented course.
8.	Musa et al. (2021)	Mathematics teachers believe GeoGebra has the potential to improve students ability to grasp concepts in geometry. However, due to time restrictions, a lack of knowledge, exposure to, and experience using GeoGebra, and a lack of facilities, the use of GeoGebra in mathematics education is currently insufficient.
9.	Bueno et al. (2021)	The online course that focused on creating educational apps and puzzles using GeoGebra was effective in fostering the growth of Technological Pedagogical Content Knowledge (TPACK) among mathematics teachers. Integrating GeoGebra in the classroom necessitates that mathematics teachers come up with novel pedagogical approaches as well as fresh approaches to regulating the classroom atmosphere because it can increase teacher professionalism.
10.	Baye et al. (2021)	Students' conceptual grasp of limits can be improved by integrating GeoGebra with a multi-teaching approach driven by the APOS theory.
11.	Manganyana et al. (2020)	In comparison to the conventional chalk-and-talk method, students' confidence increased, and they were enthusiastic about learning quadrilaterals with GeoGebra.
12.	Za'ba et al. (2020)	Hands-on exercises are used to teach GeoGebra in the translation classroom. When using GeoGebra in the mathematics classroom, it was discovered that both teachers and students were highly at ease.
13.	Rafi & Sabrina (2019)	The use of GeoGebra in the learning of high school geometry transformation can develop the professionalism of mathematics teachers through workshops.
14.	Machromah et al. (2019)	GeoGebra was helpful in assisting students in comprehending the concepts of integral calculus, and it increased student motivation and made learning enjoyable.
15.	Belgheis & Kamalludeen (2018)	Teachers intention to use GeoGebra in teaching mathematics and their perceived existing competencies are positively correlated.

Discussion

The purpose of this study is to critically emphasise the users' perspective and the use of GeoGebra in mathematics education in the chosen literature. The findings of the study show that there were many studies on the use of GeoGebra software conducted from 2018 to 2023. This shows that researchers are interested in studying the use of GeoGebra in mathematics

education from the aspect of how to use it and from the perspective of GeoGebra users. This is because the GeoGebra software is very beneficial in mathematics education. In line with the findings of this study, Diva et al. (2023) stated that this software encourages students' active problem-centred solving by enabling mathematical experiments, interactive exploration, and exploratory teaching. Interestingly, GeoGebra software can develop students' thoughts and ideas in an interesting visual form (Kim & Ali, 2020).

The results of this study show that most users hold favourable views of GeoGebra and find it an effective pedagogical tool. Most researchers found that users have positive perspectives and perceptions about using GeoGebra (Owusu et al., 2023; Saralar-Aras, 2022; Bedada & Machaba, 2022; Handayani et al., 2022; Manganyana et al., 2020; Rafi & Sabrina, 2019; Machromah et al., 2019; Belgheis & Kamalludeen, 2018). Users believe that this software can enhance their understanding of mathematics concepts and increase their motivation and performance in learning mathematics. A study by Manganyana et al. (2020) proved that GeoGebra can enhance students performance and enthusiasm for learning quadrilaterals. Besides, Za'ba et al. (2020) found that both teachers and students used GeoGebra easily. This is because it has a tutorial to make it easier for users to understand how to use it. According to Belgheis & Kamalludeen (2018), teachers' beliefs and competencies can influence the implementation of GeoGebra in mathematics education. This means that when teachers are confident and have high competency in using GeoGebra, they will implement it effectively in the classroom.

For the implementation of GeoGebra in mathematics education, the results revealed that the use of GeoGebra in mathematics education can be seen as being used all over the world, including in Malaysia, Indonesia, South Africa, Ethiopia, Brazil, Turkey, Ghana, and Ecuador. According to Saralar-Aras (2020), middle school mathematics teachers used this software to provide visual representations, facilitate student learning, raise engagement, lessen burden, and save time. Moreover, the use of GeoGebra in mathematics education requires teachers to diversify teaching methods and class management (Bueno et al., 2021). This can be proved through these results: there are users using GeoGebra through problem-based learning (Suratno & Waliyanti, 2023), flipped learning (Ishartono et al., 2022), GeoGebra-assisted CPS learning (Handayani et al., 2022), a multi-teaching approach (Baye et al., 2021), and hands-on activity (Za'ba et al., 2020). In addition, various mathematical topics are suitable for using GeoGebra as a teaching aid, such as polar coordinates (Owusu et al., 2023), geometry (Musa et al., 2021), quadrilaterals (Manganyana et al., 2020), translation (Zaba et al., 2020), integral calculus (Macromah et al., 2019), and geometry transformation (Rafi & Sabrina, 2019). However, the implementation of GeoGebra in the mathematics classroom can be limited because of lesson planning, social context, time management, classroom organisation, a lack of knowledge, exposure to, and experience using GeoGebra, and a lack of facilities (Sarlar-Aras, 2022; Musa et al., 2021).

In conclusion, the application of GeoGebra in mathematics education and the users' viewpoint are the main topics of this study. According to the results, there is a lot of interest in researching and using GeoGebra software in mathematics education since it promotes 21st century learning. The majority of users have favourable opinions of GeoGebra and see it as a useful educational tool that improves students' understanding, motivation, and performance in mathematics. GeoGebra is being used by teachers all across the world for its visual representations, student engagement, time savings, and variety of teaching styles. Although GeoGebra has proven to be useful, there are still obstacles to its efficient implementation in

terms of lesson planning, social context, time management, classroom organisation, expertise, and experience.

Conclusion

In summary, the study revealed that mathematics teachers and students, who utilised GeoGebra exhibited more positive attitudes towards mathematics compared to those employing traditional teaching methods. The use of GeoGebra is believed to offer several advantages, such as elevating the professionalism of educators, serving as a visual aid in mathematics instruction, improving problem-solving skills, and enhancing student achievement and motivation. The literature review also suggests that GeoGebra can be applied across various mathematical topics and can be integrated with diverse teaching strategies. However, despite GeoGebra's widespread global use, mathematics instructors encounter challenges when integrating it into the classroom, stemming from factors such as time constraints, classroom management, and lesson planning. Mathematics teachers need to possess a high level of technological, pedagogical, and content expertise to ensure the effective utilization of GeoGebra. This is crucial because their perspective can significantly impact how GeoGebra is employed in mathematics education. Consequently, further in-depth research should be conducted to address the challenges faced by mathematics teachers, with the aim of enabling all educators to effectively incorporate GeoGebra into mathematics learning. In conclusion, GeoGebra proves to be a valuable tool for facilitating remote learning, and as technology continues to play a more prominent role in education, its usage is likely to become even more widespread.

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