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A systematic literature review on implementation of GeoGebra: Benefits and challenges in mathematics education

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Abstract

GeoGebra is a popular dynamic geometry software that is used by many teachers and students throughout the globe to understand mathematical concepts better. Its versatility to be used online and offline has opened up a new horizon in multiple learning environments in the mathematics education field. Whether it is blended, online, or even in a traditional learning environment, a literature study regarding its benefits and challenges is still relatively rare. This study follows a Systematic Literature Review (SLR) by utilizing PRISMA's meta-synthesis formulation to identify the benefits and challenges of the application of GeoGebra in different learning environments, which initially identify 527 literature and through a deep screening inclusion and exclusion criteria, a result of matching 33 literature studies has selected and shown that the most mentioned benefits of GeoGebra in multiple learning environment are its capabilities to improve mathematical concept understanding, while the most mentioned challenges itself is showing a requirement for supplementary module to assist GeoGebra implementation. These findings are crucial for teachers or educational institutions to set up a better learning component, media, or tools before integrating GeoGebra into the learning process.

Keywords:
Blended learning, Geogebra, Online learning, Systematic literature review, Traditional learning

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1. INTRODUCTION

Today, visual media in a form of images, video or audio are extremely needed to help student accelerate visualization of mathematical's abstract concept. By merging technology into learning process, it might provide teacher with a new learning alternative as a learning media such as online and blended learning environment (Daulay et al., 2021; Hidayat et al., 2023; Iparraguirre-Villanueva et al., 2023; Kim & Md-Ali, 2017; Muqorobin & Rozaq Rais, 2020; Za'ba et al., 2020). The integration of technology into the mathematical education landscape has

opened up new avenues for enhancing the learning experience. One such technological tool that has gained significant attention in mathematics education is GeoGebra, a dynamic mathematics software that can be used to represent and visualize a mathematical concept (Diković, 2009; Doruk et al., 2013; Tamam & Dasari, 2021).

While there might be limitless possibilities of research related to GeoGebra with different variables such as self-efficacy, learning reflection (Hardiyanto et al., 2024; Purwasih et al., 2020; Zetriuslita et al., 2020), spatial skill (Baranová & Katreničová, 2018; Sari et al., 2022), or mathematical concept interpretation (Nasrullah et al., 2023), the extent of its integration within its learning environments remains an area that warrants further investigation. This study followed a rigorous Systematic Literature Review (SLR) methodology to synthesize the current knowledge on the potential best learning environment aspect of GeoGebra in traditional, online and blended learning environment settings, identify benefits and challenges, and highlight areas for future research. By identifying its benefits and challenges, mathematics teacher might discover the best learning method to deliver teaching material and more prepared to overcome learning obstacle.

GeoGebra is a dynamic geometry teaching and learning activity software to support the construction of points and lines in a field of mathematics. GeoGebra are capable to visualize mathematical notation such as finding the origin, endpoint and critical point changes in functions, coordinates and reflections, finding derivatives and integrals of direct functions. Many mathematics teachers are supported by GeoGebra to maximize learning effectiveness (Diković, 2009; Yildiz & Arpaci, 2024).

Blended learning, also known as hybrid learning, is a pedagogical approach that combines face-to-face instruction with online or digital elements (Nasrullah et al., 2024; Samura & Darhim, 2023; Yimer, 2022; Yustina et al., 2020). This method allows teacher to implement a more customized learning experience, as it leverages the strengths of both traditional and digital learning environment. Within this context, the integration of GeoGebra might play a significant role in enhancing the learning of mathematics, particularly in motivating the student to have a better understanding regarding mathematical concept (Septian & Monariska, 2021; Zetriuslita et al., 2020). The integration of GeoGebra in a different learning environment can provide both teacher and students with opportunities to engage in hands-on learning activities, while also benefitting from the flexibility and accessibility of online resources.

Existing research has highlighted the potential benefits of integrating GeoGebra in a learning setting. Studies have shown that the use of GeoGebra can improve problem-solving skills, particularly in areas such as analytic geometry, affective, behavioral, cognitive aspect (Arbain & Shukor, 2015; Assadi & Cretu, 2023; Frassia & Serpe, 2017; Latifi et al., 2022; Sugandi et al., 2020). Furthermore, the integration of GeoGebra can foster students' visualization abilities, which are crucial for understanding and applying mathematical concepts (Uwurukundo et al., 2022).

This study has an in-depth purposes to systematically review the literature to identify benefits and challenges in GeoGebra application on different learning environment. Therefore, this formulation of research question is (1) what are the benefits in implementing GeoGebra in various mathematical learning environment? (2) what are the challenges in implementing GeoGebra in various mathematical learning environment? and (3) what issues, suggestions and

topic developments can be identified in the research to further contribute in mathematics education?

2. METHOD

A Systematic Literature Review (SLR) was conducted to gather and synthesize the existing research on the application of GeoGebra in different learning environment such as Blended Learning and Traditional Learning (Aliyu et al., 2021; Yu et al., 2022). Systematic literature reviews was conducted to identify and discover research gap, compare hypothesis or expand a scope of a topics in specific field of study (Gough et al., 2017). The information served through SLR give a chance for stakeholder, practitioners, and researchers to obtain insight to make informed decisions in the future to close gap based on reviewing process. The review process involved begin by formulating the research questions and conceptual framework to provide a clear and relevant result. Then, search for and identify relevant literature regarding focused topics available in multiple sources. Continue the screening process and select studies based on pre-defined inclusion/exclusion criteria. Data then extracted and analyzed from the included studies by definng variable related to research question. Next step are to synthesize the findings and identify key themes and trends. Finally, interpret the results and discuss the implications for future research and practice (Wibowo & Putri, 2021).

To preserve journal quality, this research uses journal indexing category based on Science and Technology Index or known as “Sinta”, a publication indexing tier used by most researcher in Indonesia. If scopus indexes divide journal quality into Q1, Q2, Q3 and Q4, Sinta also provide similar indexes, but focused on Indonesia publication quality that divided into six tiers of S1, S2, S3, S4, S5 and S6. The similarity between Scopus indexed journal and Sinta-indexed journal is that both have a reputation for the quality of the article and the journal itself from accredited institution.

The search terms used includes "GeoGebra", "traditional learning", “online learning” and "blended learning". For this research, to ensure quality on the selected articles, the search for relevant studies was focused on high-quality standardized national journals indexed in Sinta with a tier of at least Sinta-2 indexed journal (S2), or Sinta-1 indexed journal (S1) which automatically categorized as indexed international journals in Scopus.

A total of 33 studies were included in the final analysis, after the screening and selection process. The selected studies provided valuable understanding into the use of GeoGebra in various mathematical learning environments, including its opportunities and challenges for future implementation.

The inclusion criteria for the studies were recent articles published in the past 10 years, and focused on the application of GeoGebra with sufficient explanation regarding its learning environment (traditional, online or blended learning). The exclusion criteria were: studies that did not focuses on the use of GeoGebra, does not specify or indicates its learning environment and studies that were not related to the field of mathematics or mathematics education. During the screening and selection process, the studies were evaluated based on their relevance to the research topic, the quality of the research, and the overall significance

of the findings. Therefore, the justification of each article criteria is as being mentioned on Table 1.

Table 1. Justification of article's criteria

Criteria	Justification
Published between 2014-2024	To ensure each topic or article is updated and relevant with current trend
Using Indonesian National Journal Indexing (SINTA 1 & SINTA 2)	To ensure the quality of journal obtained in Indonesia
Article published in English or Bahasa	To prevent misinterpretation of research variable due to language barrier
In correlation with Mathematics or Mathematic Education field	The purpose of this research is to align with the implementation of GeoGebra, which mainly used in Mathematics field.

All of the criteria are screened using a review procedure that refers to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) which is used systematically to answer the problem formulation. As mentioned by Putra et al. (2023), PRISMA procedure are conducted by following identification, screening and eligibility process. At identification step, all records regarding GeoGebra implementation are identified by collecting data from multiple journal publishing site and removing duplicates. Further identification are ensuring the records must be accessible in the future through a never-changing serial number or permanent link such as Digital Object Identifier (DOI). In the screening process, a records regarding GeoGebra implementation are being selected to meets sample or population criteria which is listed on at least Sinta-1 and Sinta-2 indexed journal. Then, the records are filtered by specified inclusion and exclusion criteria which has being set to ensure its relevancy with main topics. Finally, eligibility step are conducted with additional inclusion and exclusion criteria of records to synthesize variables in order to answer research question. The PRISMA procedures of this research are shown in Figure 1.

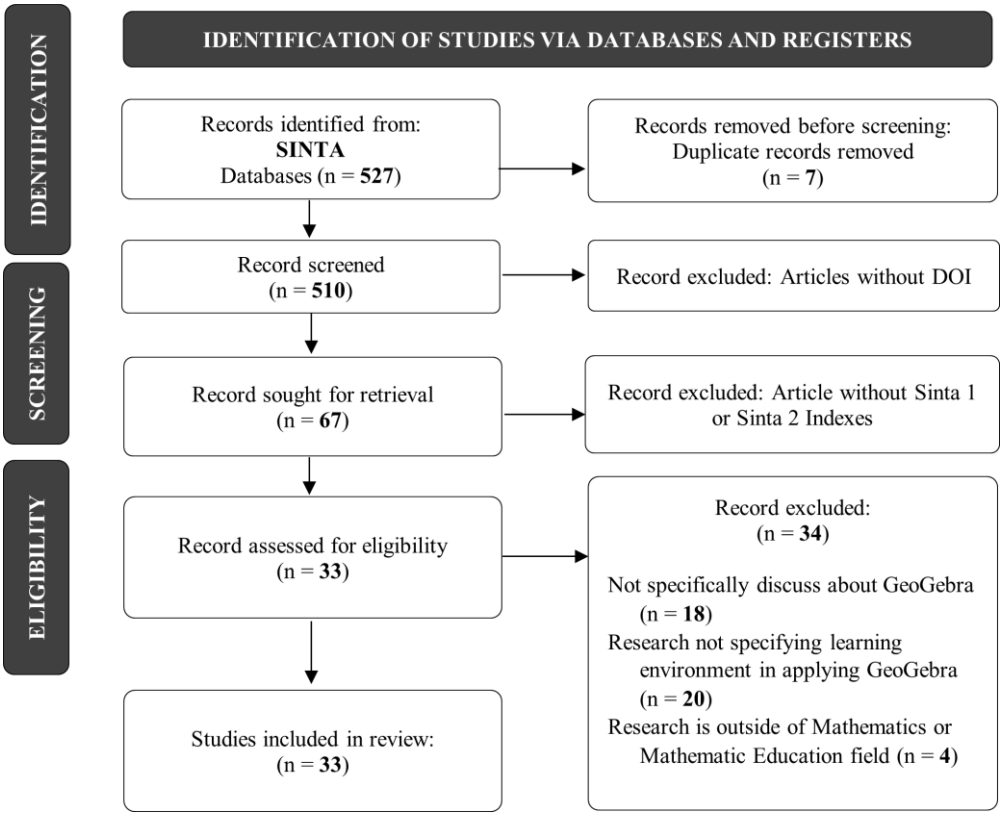

Figure 1. PRISMA procedure (Wibowo & Putri, 2021)

3. RESULTS AND DISCUSSION

3.1. Results

To ensure the data obtained from SLR procedure is up-to-date and relevant to current trends, this studies limit the publication years between 2014 and 2024. Of the 33 articles screened, 25 articles were published in the past 5 years, and the rest were published up to 2014 as shown in Figure 2.

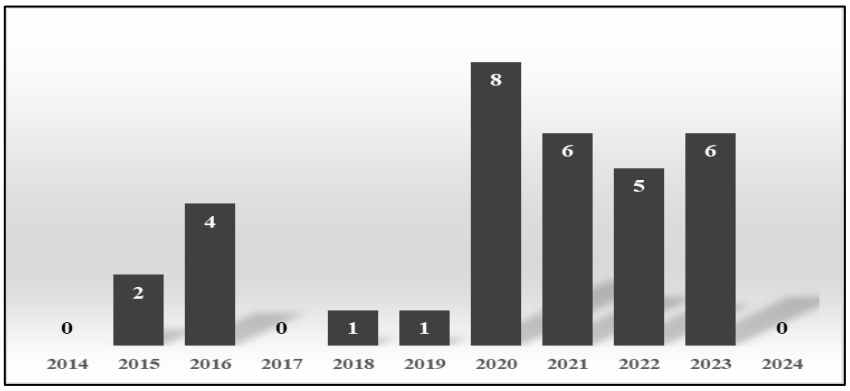

Figure 2. Distribution of screened article publication from 2014-2024

The application of GeoGebra as learning media has increased recently due to COVID-19 pandemic in 2020, which forces most learning process are organized from home to avoid continued transmission of viruses that spread from direct contact such in classroom.

In the other hand, this condition encourages mathematics teacher to find and experiment with a more effective learning environment such as online learning and blended learning. One of its effort is by integrating technological tools such as GeoGebra, in an online, offline or blended learning environment to stimulate student's learning process and capabilities.

From selected article, 21 of articles are representing a traditional learning environment with face-to-face situation where ordinary teacher-student interaction in classroom are occured, 7 articles are applying GeoGebra in online learning where there is no direct interaction and 5 articles in blended learning environment where teacher are sometimes present in classroom and sometimes organizing an online classes.

The number of screened article shows that many teacher still uses GeoGebra with direct guidance and assistance in a class full of student, since online or blended learning are not commonly used without a direct permission, instruction or special programme from educational institution or government. Teachers are normally required to attend school to fulfill their attendance obligations according to the provisions of the Ministry of Education.

Several benefits are identified from this systematic literature review such as GeoGebra' capabilities to boost mathematical concept understanding, providing more motivation and encouraging critical thinking on student. On the other side, there are several identified challenges such as GeoGebra's dependency into a supplementary learning module such as worksheet or a tutorial video regarding how to use GeoGebra. Other challenges faced by teacher and student are the limitation of device or internet availability which still become a prominent issue in various learning environment. A detailed literature review on application of GeoGebra in different learning environment are shown in Table 2.

Table 2. Systematic literature review of GeoGebra application in different learning environment

Author & Publication Year	Learning Environment	Benefits	Challenges
Asdarina and Khatimah (2021)	Traditional	Practicality, effectiveness, motivation	Supplementary learning module
Asmar and Delyana (2020)	Traditional	Learning independently, critical thinking	Limitation of visual media, content or feature, supplementary learning module
Firdayati (2020)	Traditional	Activities, motivation	Computational skill / thinking
Komar et al. (2022)	Traditional	Practicality	Internet availability, computational skill / thinking
Sari et al. (2022)	Traditional	Practicality, effectiveness	Supplementary learning module
Purwasih et al. (2020)	Traditional	Self efficacy, creative thinking, mathematical concept understanding	Student's courage / confidence
Ulfiyani et al. (2023)	Traditional	Practicality	Limitation of visual media, content or feature, supplementary learning module

Author & Publication Year	Learning Environment	Benefits	Challenges
Yullah et al. (2022)	Traditional	Effectiveness, creative thinking	Supplementary learning module
Warsitasari and Rofiki (2023)	Traditional	Logical reasoning	Computational skill / thinking
Supriadi (2015)	Traditional	Mathematical concept understanding, mathematical Communication	Technological device availability
Septian et al. (2020)	Traditional	Creative thinking, mathematical concept understanding	Supplementary learning module
Rhilmanidar et al. (2020)	Traditional	Activities, mathematical concept understanding, responses	Supplementary learning module
Rachmawati et al. (2023)	Traditional	Creative thinking	-
Nopiyani et al. (2016)	Traditional	Mathematical communication	Supplementary learning module
Saputra (2016)	Traditional	Effective, creative thinking, self-efficacy	Supplementary learning module
Oktaria et al. (2016)	Traditional	Mathematical concept understanding	-
Saputro et al. (2015)	Traditional	Activities	Supplementary learning module
Saputro (2016)	Traditional	Responses, mathematical concept understanding, mathematical communication	Computational skill / thinking
Rohaeti and Bernard (2018)	Traditional	Mathematical concept understanding	Supplementary learning module
Zetriuslita et al. (2020)	Traditional	Self efficacy, responses, self regulation	-
Mutiah et al. (2023)	Traditional	Spatial ability	-
Afrilianto et al. (2022)	Online	Creative thinking	Project-activity-cooperative learning-exercise model
Arbain (2021)	Online	Practicality, effectiveness,	Supplementary learning video
Hadi and Faradillah (2022)	Online	Problem solving, motivation	-
Sugandi et al. (2020)	Online	Creative thinking, problem solving, logical reasoning	Internet availability, Device availability
Sirad and Arbain (2021)	Online	Practicality, effectiveness, motivation	Supplementary learning module

Author & Publication Year	Learning Environment	Benefits	Challenges
Miatun and Khusna (2020)	Online	Critical thinking	Internet availability
Faizah et al. (2023)	Online	Activities, motivation, mathematical concept understanding	Internet availability, device availability, limitation of visual media, content or feature, supplementary learning module
Wijaya et al. (2023)	Blended	Motivation	Limitation of visual media, content or feature
Annisa et al. (2022)	Blended	Mathematical concept understanding, practicality, effectiveness	Internet availability, limitation of visual media, content or feature
Nurdin et al. (2019)	Blended	Mathematical concept understanding	Internet availability, device availability, limitation of visual media, content or feature
Maf'ulah et al. (2021)	Blended	Mathematical concept understanding	Internet availability, device availability
Rochim and Herawati (2021)	Blended	Mathematical concept understanding	Internet availability, device availability, monitoring

From 33 article screened for literature review, 21 articles are indicating a traditional learning environment, 7 online learning environment and 5 in blended learning environment. This literature review shows that traditional learning is the major learning environment in mathematics eduction while implementing GeoGebra into learning process, despite the condition during COVID-19 in 2020 which forced most teacher and student to conduct learning process remotely and increase blended or online learning. The distribution of each article based on its learning environment are shown in Figure 3.

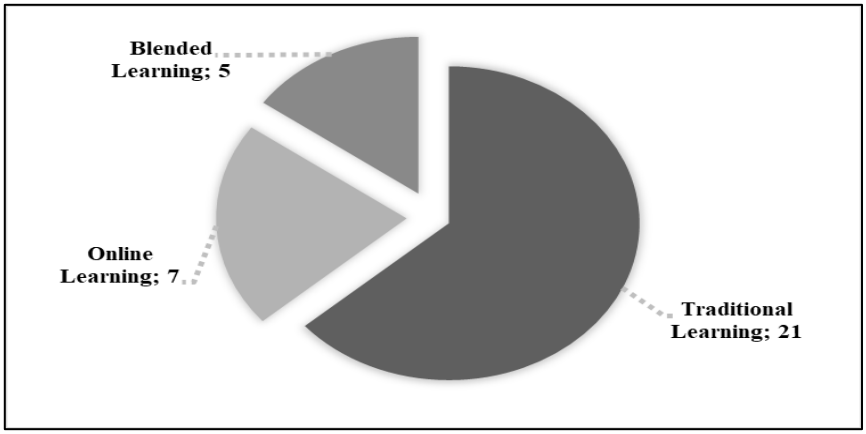

Figure 3. Distribution of screened article by its learning environment

3.1.1. Benefits of GeoGebra application in different learning environment

This study identified several factor as benefits of GeoGebra application in different learning environment. As much as 15 types of benefits were identified in the screened article, with a total of 62 mentions from 33 articles. Traditional learning has 39 identified benefits, online learning with 15 benefits and blended learning with 8 benefits. As for traditional learning, the most mentioned benefits in screened articles are mathematical concept understanding (Hidayat et al., 2024) then supported by creative thinking, practicality and effectiveness.

Table 3. Identification of benefits of GeoGebra application in different learning environment

Benefits	Traditional	Online	Blended	Total
Mathematical concept understanding	7	3	4	14
Practicality	4	2	2	8
Effectiveness	4	1	2	7
Motivation	3	3	0	6
Activities	3	2	0	5
Problem solving	0	2	0	2
Creative thinking	5	1	0	6
Critical thinking	1	1	0	2
Logical reasoning	1	1	0	2
Self-efficacy	3	0	0	3
Mathematical communication	3	0	0	3
Responses	3	0	0	3
Learning independent	1	0	0	1
Self regulation	1	0	0	1

In an online learning environment, the most mentioned benefits of GeoGebra application are motivation, mathematical concept understanding, practicality and activities. For blended learning environment, due to the limited amount of screened article, this study only identifies 9 benefits being mentioned in screened article.

As mentioned on Table 3, not every type of benefits are present on each literature. Every article discuss about different topics and identifies different benefits in GeoGebra application. For example, some articles might only studying the relation between GeoGebra implementation with pre-selected variables such as self efficacy or student's motivation.

3.1.2. Challenges of GeoGebra application in different learning environment

This study identifies a total of 43 mentioned challenges from 33 screened article. Some of challenges from GeoGebra application that is identified is that to successfully integrates it with learning process, teacher might required to provide supplementary learning

module, deal with visual media limitation of application and dealing with student's computational skill / thinking.

In a traditional learning environment, the a total of 15 identified challenges of GeoGebra application being mentioned are its requirement to be supported by supplementary learning module such as book, videos, images or presentation, becoming the most major issues that teacher and student has to overcome in learning process. Then, 8 identified challenges show that internet availability prevent further GeoGebra function to be used by student in an online and blended learning environment. Another findings is the limitation of visual media, content or feature in GeoGebra which cannot provide a complete mathematical function for teacher. All identified challenges are mentioned in Table 4.

Table 4. Identification of challenges of GeoGebra application in different learning environment

Challenges	Traditional	Online	Blended	Total
Requires a supplementary learning module	11	4	0	15
Internet availability	1	3	4	8
Limitation of visual media, content or feature	3	1	3	7
Technological device availability	1	2	3	6
Computational skill / thinking	4	0	0	4
Student's courage / confidence	1	1	0	2
Student's monitoring	0	0	1	1

In an online learning environment, a supplementary learning module becomes a significant role as main challenges in application of GeoGebra in learning process, while dependencies on internet availability also becoming a second most mentioned challenges in literature. For blended learning environment, there were only 3 type of challenges being identified from screened article, which is internet availabilities, technological device availabilities and limitation of visual media, content or features.

3.2. Discussion

Several correlative benefits from GeoGebra application are identified in this systematic literature review. In total, GeoGebra capabilities to boost mathematical concept understanding (Rohaeti & Bernard, 2018), are mentioned 14 times in either traditional (7), online (3) and blended (4) learning environment, making it as the most dominant benefits obtained from GeoGebra application in learning process in traditional, online and blended learning environment. By understanding how frequent this factor being mentioned in other literature, teacher are encouraged to use GeoGebra if student is having a hard time to understand specific mathematical concept. Several mathematical concept that could be visualized to assist student in GeoGebra are geometry, linear function and algebra (Nurdin et al., 2019; Putra et al., 2021).

In traditional and blended learning environment, GeoGebra application has shown several other benefits often mentioned in literature, such as stimulating creative thinking (5), practicality (4), effectiveness (4) problem solving skill (2) and motivation (2). This indicates the learning effectiveness and easiness of using GeoGebra to further save time and complexity in learning mathematics. In contrast to the benefits that being mentioned in an implementation of GeoGebra, the most dominant challenges the teacher face is that to

implement GeoGebra, it might requires a supplementary learning module / book to assist student. Several studies found that the supplementary module are better delivered and more effective in a form of video rather than a powerpoint slide or a direct textual copy from a books (Liburd & Jen, 2021; Sirad & Arbain, 2021).

Computational skill / thinking also play a significant role that influence the effectiveness of GeoGebra implementation in traditional learning environment, either for teacher or the student itself (Bilgin & Serin, 2022; Lainufar et al., 2021; Wassie & Zergaw, 2019; Weinhandl et al., 2020). In online and blended learning environment, the most significant challenges are coming from dependencies for internet and technological device availabilities. This further implies that before implementing GeoGebra in online or blended learning environment, teacher should ensure student to have adequate internet access and sufficient technological device such as computer, tablet or smartphones. Despite of the identified challenges, there might be a different result from a broader scope of research using non-SLR methods in various nation that is affected by a different technological development and infrastructure available in each nation. For example, Wassie and Zergaw (2019) state that their findings on challenges of GeoGebra implementation are more focused on student's computational skill, technological fluency and a backup plan if something wrong is happened with GeoGebra software.

4. CONCLUSION

This systematic literature review has identified several dominant factors that become benefits and challenges of implementing GeoGebra in various learning environments. By reviewing hundreds of literature relevant to the topics, this study obtained a total of 33 intensely screened literature studies, which showed that the most mentioned benefits of GeoGebra in multiple learning environments are its capabilities to improve mathematical concept understanding. In contrast, the most mentioned challenge itself is a requirement for supplementary modules to assist GeoGebra implementation.

Other benefits being mentioned are stimulation of creative thinking, practicality, effectiveness, problem-solving skills, and motivation, while other challenges being mentioned are limitations of visual media, content, or features from GeoGebra apps, internet, and technological device availabilities.

Despite deep literature study regarding the implementation of GeoGebra, future research is suggested also to explore the implementation of other Dynamic Geometry Software (DGS) available on the web, such as Wingeom, Cabri 3D, Pointline, WIRIS, etc, to expand its impact on different learning environment further.

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