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Original Article

Integration of GeoGebra in Learning Mathematics: Benefits and Challenges

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ABSTRACT

Technology is recognized as a vital component of modern society, making it essential for education to incorporate various technological aspects into the teaching and learning of mathematics. GeoGebra is a valuable tool that has gained attention, which enhances mathematics instruction, particularly in areas like geometry, algebra, and statistics. However, there is limited understanding of the benefits and challenges associated with using GeoGebra in mathematics instruction. Therefore, the purpose of this paper was to review existing literature on the benefits and challenges of integrating GeoGebra in a mathematics classroom. Data were collected through a documentary review and to this effect, 53 articles from four databases namely ERIC, Scopus, JSTOR, and ProQuest were reviewed. After analyzing the data through content analysis and categorization, the results revealed that GeoGebra: demystifies mathematical concepts for learners; improves learners' mathematical abilities and representation skills; enhances students' active construction of knowledge; boosts students' mathematical achievement; improves students' attitudes and perceptions toward mathematics learning; empowers students to visualize abstract mathematical concepts; creates an enjoyable learning environment; and fosters the development of 21st-century skills among learners. Nevertheless, the integration of GeoGebra in mathematics instruction presents several challenges. These include teachers' lack of proficiency in using ICT, insufficient training in ICT, limited access to technological equipment, inadequate guidance on interpreting GeoGebra outputs, a high student-to-teacher ratio, and time constraints. Despite the many benefits of GeoGebra, teachers must receive adequate training to equip them with the knowledge and skills necessary to effectively integrate this tool into their teaching and learning of mathematics.

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INTRODUCTION

The world has undergone a technological revolution that has impacted various fields, including education (Raja & Nagasubramani, 2018). As a result, educational systems are encouraged to adopt strategies for integrating Information and Communication Technology (ICT) to enhance pedagogical practices across all disciplines (Oulmaati et al., 2017). As early as the 20th century, the National Council of Teachers of Mathematics (NCTM) in the United States outlined the role of technology in mathematics teaching and learning. According to NCTM, both teachers and students should have regular access to ICT resources that support and promote mathematical reasoning, problem-solving, communication, and sense-making (Haji, 2019). Asare et al. (2023) argue that effective educators leverage the potential of ICT to enhance students' understanding, stimulate their interest, and improve their proficiency in mathematics.

According to Muslim et al. (2023), utilizing technology in mathematics instruction is crucial to developing individuals who are highly skilled and prepared to tackle the challenges of the 21st century. Thus, the transformative perspective on ICT in mathematics education urges a re-examination of the pedagogical approaches and curricula suitable for a new generation that engages with innovative tools (Makrakis, 2014). Furthermore, appropriate use of ICT in the classroom should be ensured to benefit both the teachers' pedagogical actions and the students' learning experiences (Maharjan et al., 2022; Uwurukundo et al., 2022a). Over the past few decades, mathematical software programs have undergone significant advancements (Zengin et al., 2012). As a result, many of these software programs are now widely used for mathematics instruction around the world. Popular mathematical tools include Geometer's Sketchpad (GSP), Autograph, Maple, MATLAB, Mathematica, graphing calculators, and more (Nordin et al., 2010; Tajudin, 2013; Srinivas et al., 2023). Two prominent types of software designed for teaching and learning mathematics are Computer Algebra Systems (CAS) and Dynamic Geometry Software (DGS) (Gonçalves et al., 2018). These two types of software have been combined into a single program called GeoGebra, which integrates their functionalities to enhance mathematics education (Hohenwarter & Fuchs, 2004; Hohenwarter & Jones, 2007).

GeoGebra is a valuable tool for teaching mathematics (Diković, 2009). It features a user-friendly interface and a web-based platform, making it accessible to users worldwide and offering a wide range of mathematical resources (Velichova, 2011). The software was developed with the idea of combining geometry, algebra, and calculus - fields of mathematics that most other similar software typically handles separately - into a single, open-source, and user-friendly package (Hohenwarter & Fuchs, 2004). This software is widely used globally because it is free to use with no licensing requirements, and it is easier to navigate compared to other mathematics teaching software (Muslim et al., 2023). GeoGebra is available in over fifty languages and can be downloaded on computers or mobile devices (Handal et al., 2013).

In sub-Saharan African countries, governments acknowledge the significance of digital technologies in education (Chimbunde & Jakachira, 2024). These technologies are seen as essential for preparing learners and educators to succeed in a highly digitized economy and a fast-changing job market (Haleem et al., 2022). However, several studies have shown that users of digital technology face challenges, particularly concerning internet connectivity and low bandwidth (Golding & Batiibwe, 2020; Kibirige, 2023; Nyakito et al., 2021; Nakitto et al., 2022). Using GeoGebra software is particularly beneficial in such cases because it is a free tool that can be accessed offline at any time once downloaded onto a computer (Tamam & Dasari, 2021). GeoGebra is a relatively new addition to the education system in sub-Saharan Africa, and as a result, there is limited information about its benefits and challenges in the teaching and learning of mathematics. It is essential to explore existing findings regarding its applications to help educators

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and students understand the advantages of using GeoGebra, as well as the potential challenges they may encounter. By increasing awareness of the software among both teachers and students, its integration into mathematics classrooms can be facilitated. Thus, the specific objectives of this review were to establish:

- The benefits of integrating GeoGebra into mathematics learning.
- The challenges associated with incorporating GeoGebra into mathematics instruction.

METHODOLOGY

The review was qualitative (Oranga & Matere, 2023), and data were collected through documentary analysis (Wills, 2022) of published articles sourced from four databases: ERIC, Scopus, JSTOR, and ProQuest. The initial search terms included "GeoGebra," "integration of GeoGebra," "challenges of using GeoGebra," "advantages of using GeoGebra," "outcomes of using GeoGebra," and "the impact of integrating GeoGebra in the learning of mathematics." This search resulted in 810 references. To refine the selection, a specific inclusion criteria for the articles to be analyzed was established. Articles had to be peer-reviewed, written in English, and published between 2015 and 2024. After conducting the initial screening, 110 articles remained for further evaluation. Theoretical studies were then excluded, leaving 82 experimental articles. Ultimately, 53 studies were considered for this review.

Data were analyzed using content analysis (Bengtsson, 2016) and categorization (Parland-von Essen et al., 2018). In the content analysis, the benefits and challenges of integrating GeoGebra in mathematics instruction from each article were identified first. These were then organized into broader themes, with each theme being identified if a particular benefit or challenge appeared three or more times in the analysis. The findings were interpreted and discussed with their implications for policy and practice. Further details on the findings and their discussion are presented in the following subsequent sections.

FINDINGS

Benefits of using GeoGebra in Teaching and Learning Mathematics

In this review, it was revealed that GeoGebra: demystifies mathematical concepts for learners; improves learners' mathematical abilities and representation skills; enhances students' active construction of knowledge; boosts students' mathematical achievement; improves students' attitudes and perceptions toward mathematics learning; empowers students to visualize abstract mathematical concepts; creates an enjoyable learning environment; and fosters the development of 21st-century skills among learners. The details are given subsequently.

Demystifies Mathematics Concepts for Learners

Mwingirwa and Miheso-O'Connor (2016) argued that certain mathematical concepts, such as geometry, are inherently abstract. However, many scholars worldwide have demonstrated that integrating GeoGebra into teaching and learning can clarify various mathematical concepts. For example, research has shown its effectiveness in areas such as geometry (Simbolon & Siahaan, 2020; Pamungkas et al., 2019; Mukhtar et al., 2021); linear functions (Ogbonnaya & Mushipe, 2020); geometric transformations (Musa et al., 2021; Mukamba & Makamure, 2020; Dahal et al., 2019); polar coordinates (Owusu et al., 2023); limits and functions (Munyaruhengeri et al., 2023; Baye et al., 2021); algebra (Azucena et al., 2022); circle theorems (Thapa et al., 2022); and calculus (Machromah et al., 2019) among others.

Improves Learners' Mathematical Abilities and Representation Skills

Whereas mathematical representation refers to the ability to express mathematical concepts through drawings, equations, and written text (Utami et al., 2019), mathematical ability is the capability to perform mathematical tasks and effectively solve problems (Blacksmith, 2020). The use of GeoGebra has been shown to enhance both mathematical skills and representation skills, which are crucial for solving mathematical problems. Research indicates that employing GeoGebra during mathematics

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instruction significantly improves both mathematical abilities and representation skills for the learners (Rabi et al., 2021; Machromah et al., 2019; Azucena et al., 2022; Uwurukundo et al., 2022b; Simbolon & Siahaan, 2020; Baye et al., 2021; Muslim et al., 2023; Kim & Md-Ali, 2017).

Enhances Students' Active Knowledge Construction

Knowledge construction is the process through which students actively build their understanding of concepts by engaging in exploration, reflection, and interaction (Chand, 2023). This process involves deriving meaning from the information and experiences acquired through various learning activities and projects (Jumaat et al., 2017). Research indicates that students connect knowledge most effectively in dynamic social classrooms, where they negotiate their understanding through interaction and diverse approaches (Kober, 2015). For example, while Dahal et al. (2019) found that GeoGebra facilitates students in becoming active knowledge constructors, Thapa et al. (2022) revealed that it enhances student-centred teaching and learning, enabling students to take a more active role in constructing mathematical knowledge. Additionally, Munyaruhengeri et al. (2023) demonstrated that using GeoGebra improves conceptual and procedural knowledge.

Boosts Students' Mathematics Achievement

Mathematical achievement refers to a student's proficiency in mathematics gained through knowledge and skills at a specific stage (Pandey, 2017). This is often measured by achievement test scores (Galangco, 2023). Research indicates that GeoGebra can enhance mathematical performance. For example, Ogbonnaya and Mushipe (2020) found that students taught using GeoGebra improved their skills in graphing linear functions and interpreting representations. Similar positive results were noted in studies by Owusu et al. (2023), Baye et al. (2021), Singh (2018), and Saha et al. (2010), showing that students using GeoGebra had a better understanding of geometric concepts than those taught traditionally.

Improves Students' Attitudes and Perceptions toward Mathematics Learning

Jaelani and Rahmah (2019) defined student perceptions as the thoughts students have about their learning experiences. Some students often perceive mathematics as difficult (Kebede, 2023). However, GeoGebra has been shown to improve attitudes and perceptions in students due to its dynamic, interactive nature (Açıkgül, 2021). Engaging students with visual representations and hands-on manipulation of mathematical concepts fosters a positive and exploratory attitude. This software makes abstract concepts more tangible, enhancing curiosity and confidence, thus transforming mathematics from challenging to approachable (Mudaly & Fletcher, 2019). For instance, Owusu et al. (2023) found that students had positive attitudes toward using GeoGebra for learning polar coordinates, and Bedada and Machaba (2022) reported similar findings for differential calculus. Comparable results were noted by Uwurukundo et al. (2022b) and Puotier et al. (2023).

Empowers Students to Visualize Abstract Mathematical Concepts

One primary goal of teaching mathematics is the acquisition of formal, abstract concepts (Verschaffel et al., 2012). Visualization plays a crucial role in connecting these abstract ideas with concrete representations (Asare et al., 2023). It helps students observe patterns and relationships that might remain hidden in traditional methods (Yilmaz & Argun, 2018). Tools like GeoGebra allow students to interactively manipulate geometric objects and explore mathematical properties (Hohenwarter & Jones, 2007). Studies by Tamam and Dasari (2021) and Dahal et al. (2022) show that GeoGebra aids in visualizing and understanding abstract concepts, with similar findings reported by Mukamba and Mukamure (2020) and Mthethwa et al. (2020). In these cases, GeoGebra enabled students to effectively justify their claims.

Creates an Enjoyable Learning Environment

A good learning environment, whether physical or virtual, supports students in acquiring and applying knowledge (Kokko & Hirsto, 2021). It encompasses the physical, social, and emotional surroundings that

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influence learning (Baars et al., 2023). A positive environment is essential for student success, while an unsafe one can hinder learning. Research indicates that integrating GeoGebra in math education fosters an enjoyable learning atmosphere (Ocal, 2017). Zengin and Tatar (2017) found that GeoGebra encourages active knowledge construction, while Yerizon et al. (2021) reported it enhances motivation and understanding of concepts. Additionally, Bedada and Machaba (2022) noted positive student perceptions of GeoGebra in differential calculus. Joshi and Singh (2020) highlighted that engaging with GeoGebra promotes a favourable attitude toward mathematics, nurturing both understanding and appreciation for the subject (Celen, 2020).

Fosters the Development of 21st Century Skills among Learners

21st-century skills are a set of skills that are essential for success in today's world. These skills include critical thinking, creativity, collaboration, communication, information literacy, media literacy, technology literacy, and leadership (Chen, 2021) among others. Research shows that students who use GeoGebra for mathematics instruction perform better in analytical thinking, generalization, abstract thinking, representation, and logical reasoning (Kim & Md-Ali, 2017; Azucena et al., 2022). For instance, in the study by Gurmu et al. (2024), students collaborated in small groups while using GeoGebra, which helped them enhance their communication and collaboration skills alongside their conceptual understanding.

The Challenges Associated with Incorporating GeoGebra into Mathematics Instruction

The use of GeoGebra in teaching and learning mathematics provides valuable tools for teachers to enhance their instructional practices. However, this review reveals several challenges it presents. These include teachers' lack of proficiency in using ICT, insufficient training in ICT, limited access to technological equipment, inadequate guidance on interpreting GeoGebra outputs, a high student-to-teacher ratio, and time constraints. The details are given in the subsequent sections.

Teachers' Lack of Proficiency in Using ICT

Incompetence refers to the inability to successfully perform a task or meet expectations (Range et al., 2012). Teachers and students worldwide are encouraged to become familiar with 21st-century skills, which include ICT competence (Thapa et al., 2022). ICT competence encompasses the knowledge and skills that teachers need to effectively integrate ICT into their pedagogical practices (Vanderlinde et al., 2014). This competence is crucial in teachers' incorporation of ICT into classroom instruction and learning (Bervell & Umar, 2017). Since ICT is a relatively recent addition to the education systems in many Sub-Saharan African countries, many teachers still lack the necessary skills and adequate experience, which limits their ICT competence (Nyakito et al., 2021). Supporting this issue, studies conducted by Musa et al. (2021) and Wassie and Zergaw (2019) revealed that the use of GeoGebra is hindered by a lack of competence among teachers. Additionally, Agyei and Benning (2014) discovered that pre-service teachers were often unaware of how to design GeoGebra-based lessons.

Insufficient Training in Using ICT

Hillmayr, Ziernwald, Reinhold, Hofer, and Reiss (2020) emphasized that training in using digital tools is essential for teachers. They argued that educators need initial training to acquire the skills, knowledge, and attitudes necessary for effectively integrating ICT into their pedagogical practices. Without adequate training, teachers may struggle to incorporate ICT into their classrooms. For instance, Nyakito et al. (2021) discovered that teachers lacked sufficient opportunities for pre-service training in ICT use. Their limited knowledge and skills in this area were primarily due to inadequate training during their teacher preparation programs. Additionally, they noted that the in-service teachers often did not address their specific subject ICT needs, focusing instead on general, basic ICT skills. Similarly, Fernandez and Condori (2023) pointed out a particular deficiency in training related to using GeoGebra software. However, Bingimlas (2009) highlighted that the issue of ICT training is multifaceted; it requires not only instruction in basic ICT skills but also subject-specific pedagogical training for teachers.

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Limited Access to Technological Equipment

Implementing GeoGebra in the classroom highlights the digital divide among 21st-century teachers, primarily due to a lack of access to technological equipment (Fernandez & Condori, 2023). Kibirige (2023) found that teachers in rural schools in Sub-Saharan Africa face significant challenges, such as inadequate access to computers, tablets, and other ICT tools. Many Sub-Saharan schools lack electricity or solar energy (Koima, 2024). Nyakito et al. (2021) concurred, noting that while teachers are eager to use technology in their classrooms, they are hindered by insufficient ICT resources. The absence of these resources stifles efforts to enhance knowledge and skills related to integrating GeoGebra into mathematics lessons, putting students at a disadvantage when it comes to exploration and practice (Mokotjo & Mokhele, 2021). This finding is supported by Musa et al. (2021) and Muweesi et al. (2021), who discovered that the lack of technological instruments negatively impacts teaching. In the study conducted by Ubi et al. (2018), the integration of GeoGebra in mathematics instruction was similarly limited by inadequate teaching materials.

Inadequate Guidance on Interpreting GeoGebra Outputs

Comprehensive teaching instructions are those that are complete and systematic, encompassing all necessary components and addressing various modes of communication and literacy skills to support student success (Angulo, 2023). They are vital because they help students understand and complete activities as expected, while also aiding teachers in achieving their educational objectives (Wang, Pascarella, Nelson Laird, & Ribera, 2015). However, the output from GeoGebra has faced criticism for its lack of comprehensive instructions. For instance, a study by Munyaruhengeri et al. (2023) highlighted that GeoGebra's output does not provide detailed instructions. They noted that some features require specific content knowledge not covered in the GeoGebra packages, leading to issues such as incorrect automatic representations of discontinuous graphs. Similarly, research by Wassie and Zergaw (2019) found that both students and teachers struggled with some commands in the input bar, particularly those who had no prior programming experience.

A High Student-to-Teacher Ratio

A high student-to-teacher ratio (STR) occurs when there are more students than teachers in a school (Schwartz, Schmitt, & Lose, 2012). In the United States, the average STR is 20 students per teacher (Solheim & Opheim, 2019), whereas in most Sub-Saharan African countries, it averages 50 students per teacher (UNESCO, 2021). According to Koc and Celik (2015), a high STR can make it difficult for teachers to give each student the attention they need to succeed, which may lead to gaps in learning and underperformance. For instance, a study by Wassie and Zergaw (2019) found that the student-to-teacher ratio posed a challenge for the integration of GeoGebra. As a result, not all students were able to access GeoGebra, and those who did often did not receive sufficient support from their teacher.

Time Constraints

Agyei and Benning (2014) emphasized that teachers require sufficient time to support each student, particularly in classrooms with high enrollment. Musa et al. (2021) highlighted that limited time allocations pose challenges for teachers, which negatively affects student learning (Muweesi et al., 2021). For instance, Mulwa's (2015) study revealed that insufficient time led to inconsistent class practices regarding the use of GeoGebra. Consequently, teachers were unable to provide adequate feedback, assess students, and address individual learning needs. Similar conclusions were reached in the studies conducted by Mwingirwa and Miheso-O'Connor (2016) and Musa et al. (2021).

DISCUSSION

This review highlighted the benefits of using GeoGebra in mathematics learning and the challenges teachers encounter during math instruction. It has been established that GeoGebra: demystifies mathematics concepts for learners; improves learners' mathematical abilities and representation skills; enhances students' active construction of knowledge; boosts students' mathematical achievement; improves students' attitudes and perceptions toward mathematics

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learning; empowers students to visualize abstract mathematical concepts; creates an enjoyable learning environment; and fosters the development of 21st-century skills among learners. The significant benefits of GeoGebra highlight its effectiveness in providing interactive and dynamic learning experiences for students. This supports the argument for integrating the software into the education curriculum and suggests its potential to transform the educational landscape. According to Bulut et al. (2016), GeoGebra is most effective when it is effectively incorporated into mathematics instruction across all levels of education, from primary school to postgraduate studies.

To effectively utilize GeoGebra, teachers must address the challenges they face in integrating it into their pedagogical practices. This review highlights some of these challenges, which include: teachers' lack of proficiency in using ICT, insufficient training in ICT, limited access to technological equipment, inadequate guidance on interpreting GeoGebra outputs, a high student-to-teacher ratio, and time constraints. These findings yield four key implications.

First, to enhance teachers' proficiency in using GeoGebra, specific training on the software is essential. Hafeez (2021) noted that targeted training can improve teachers' skills and productivity. While technology training often focuses on basic skills (Williams, 2017), it frequently lacks emphasis on subject-specific applications. This gap can lead teachers to revert to traditional methods, limiting students' opportunities for deeper understanding and engagement in mathematics (Singh, 2018). Therefore, comprehensive training on GeoGebra is crucial for developing teachers' Technological Pedagogical Content Knowledge (TPACK) as highlighted by Khalil et al. (2017) and Yildiz and Gokcek (2018).

Second, governments should not only recognize the growing importance of ICT in education and implement relevant policies for schools, but they should also provide necessary technological equipment, such as computers (Hall & Lundin, 2024). When students have sufficient computers, teachers can design lesson plans catering to each student's learning style, pace, and interests (Uwurukundo et al., 2022b). This enables students to learn more effectively by utilizing the identified benefits in this review.

Third, the finding that there is insufficient guidance on interpreting GeoGebra outputs provides valuable feedback for Markus Hohenwarter, the founder of GeoGebra. According to Henderson et al. (2021), feedback is instrumental in helping individuals identify areas for improvement, recognize their strengths, and reinforce positive habits. Thus, this constructive feedback will help Markus Hohenwarter identify specific areas for improvement, enabling him to focus on enhancing the software by offering clearer instructions for using GeoGebra.

Fourth, to tackle the high student-to-teacher ratio, teachers could implement shift-based teaching, reducing class sizes for more engagement. Smaller classrooms encourage student discussion, and collaboration, and allow teachers to provide personalized guidance and feedback (Zayed, 2016). This setting fosters stronger teacher-student connections and facilitates easier classroom management (Finn, 2019), enabling differentiated instruction that caters to individual learning styles. As a result, students in smaller classes often achieve higher test scores and better outcomes (Wright et al., 2019). Additionally, the support provided in smaller classes helps students use tools like GeoGebra independently, easing the teaching burden.

CONCLUSION

The integration of GeoGebra into mathematics education offers numerous benefits. However, despite its proven advantages, there are challenges associated with its implementation. To address these challenges, it is crucial to provide teachers with training that equips them with the necessary knowledge and skills to effectively use GeoGebra. Furthermore, mathematics teachers need to have a strong foundation in content knowledge. This preparation enables them to apply technology and pedagogical methods effectively, ultimately enhancing the teaching and learning process and supporting students' attainment of conceptual understanding.

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Data availability

All data generated and analyzed during this study are included in this published article.

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Ethics approval

The Makerere University School of Social Sciences Research Ethics Committee exempted this study from research clearance.

Consent to Participate

Given that the study was theoretical and did not involve human participants, there was no need for informed consent.

Competing interests

The author declares no competing interests

REFERENCES

Açıkgül, K. (2022). Mathematics teachers' opinions about a GeoGebra-supported learning kit for teaching polygons. *International Journal of Mathematical Education in Science and Technology, 53*(9), 2482- 2503. https://doi.org/ 10.1080/0020739X.2021.1895339

Agyei, D. D., & Benning, I. (2014). Pre-service teachers' use and perceptions of GeoGebra software as an instructional tool in teaching mathematics. *Journal of Educational Development and Practice*, *5*(1), 21-46.

Angulo, J. C. L. (2023). The importance of instruction-giving to better students' performance of class activities in English lessons. *Ciencia Latina Revista Científica Multidisciplinar*, *7*(3), 3449-3464. http://dx.doi.org/10.37811/cl_rcm.v7i3.6419

Asare, S., Agyeman, K. D., Nyarko, J., Opoku-Mensah, N., Fokuo, M. O., Owusu-Mintah, C., & Asamoah, R. (2023). The role of ICT in teaching and learning mathematics at College of Education: a systematic review. *Journal of Education and Practice*, *14*(12), 70-77. https://doi.org/10.7176/JEP/14-12-06

Azucena, L. J. R., Gacayan, P. J. L., Tabat, M. A. S., Cuanan, K. H., & Pentang, J. (2022). GeoGebra intervention: how have students' performance and confidence in Algebra advanced? *Studies in Technology and Education*, *1*(1), 51-61.

Baars, S., Schellings, G. L. M., Joore, J. P., & Van Wesemael, P. J. V. (2023). Physical learning environments' supportiveness to innovative pedagogies: students' and teachers' experiences. *Learning Environments Research*, *26*(2), 617-659.

Baye, M. G., Ayele, M. A., & Wondimuneh, T. E. (2021). Implementing GeoGebra integrated with multi-teaching approaches guided by the APOS theory to enhance students' conceptual understanding of limit in Ethiopian Universities. *Heliyon*, *7*(5), 1-13.

Bedada, T. B., & Machaba, M. F. (2022). Investigation of student's perception learning calculus with GeoGebra and cycle model. *EURASIA Journal of Mathematics, Science and Technology Education, 18*(10), 1-19. https://doi.org/10.29333/ejmste/12443

Bengtsson, M. (2016). How to plan and perform a qualitative study using content analysis. *NursingPlus Open*, *2*, 8-14. https://doi.org/10.1016/j.npls.2016.01.001

Bervell, B., & Umar, I. N. (2017). A decade of LMS acceptance and adoption research in sub-Sahara African higher education: A systematic review of models, methodologies, milestones and main challenges. *EURASIA Journal of Mathematics, Science and Technology Education*, *13*(11), 7269–7286.

Bingimlas, K. A. (2009). Barriers to the successful integration of ICT in teaching and learning environments: A review of the literature. *EURASIA Journal of Mathematics, Science and Technology Education*, *5*(3), 235-245.

Article DOI: https://doi.org/10.37284/eajes.7.4.2454

Blacksmith, N. (2020). Mathematical abilities. In: Zeigler-Hill, V., Shackelford, T.K. (eds) Encyclopedia of Personality and Individual Differences. Springer, Cham. https://doi.org/10.1007/978-3-319-24612-3_984

Bulut, M., Akçakın, H. Ü. Kaya, G., & Akçakın, V. (2016). The effects of GeoGebra on third-grade primary students' academic achievement in fractions. *Mathematics Education*, *11*(2), 347-355.

Celen, Y. (2020). Student opinions on the use of GeoGebra software in mathematics teaching. *Turkish Online Journal of Educational Technology-TOJET*, *19*(4), 84-88.

Chand, S. P. (2023). Constructivism in education: Exploring the contributions of Piaget, Vygotsky, and Bruner. *International Journal of Science and Research, 12(7), 274-278.* http://dx.doi.org/10.21275/SR23630021800

Chen, D. (2021). Toward an understanding of 21st-century skills: From a systematic review. *International Journal for Educational and Vocational Guidance*, 23(2), 1-20. https://doi.org/10.1007/s10775-021-09511-1

Chimbunde, P., & Jakachira, G. (2024). Threading through the needle of digital education in Sub-Saharan Africa: understanding the concerns of university lecturers. *Interactive Learning Environments*, 1- 13. https://doi.org/10.1080/10494820.2024.2335479

Dahal, N., Shrestha, D., & Pant, B. P (2019). Integration of GeoGebra in teaching and learning geometric transformation. *Journal of Mathematics and Statistical Science*, 5(12), 323-332.

Dahal, N., Pant, B. P., Shrestha, I. M., & Manandhar, N. K. (2022). Use of GeoGebra in teaching and learning geometric transformation in school mathematics. *International Journal of Interactive Mobile Technologies, 16*(8), 65–78. https://doi.org/10.3991/ijim.v16i08.29575

Diković, L. (2009). Applications GeoGebra into teaching some topics of mathematics at the college level. *Computer Science and Information Systems*, 6(2), 191–203. https://doi.org/10.2298/csis0902191D

Fernandez, R. A., & Condori, A. P. (2023). Digital and 21st-century competencies: challenges and difficulties in the teaching and learning of mathematics by Ecuadorian teachers. *PriMera Scientific Engineering, 2,* 13-24. https://doi.org/10.56831/PSEN-02-031.

Finn, J. D. (2019). Academic and non-cognitive effects of small classes. *International Journal of Educational Research*, *96*, 125-135. https://doi.org/10.1016/j.ijer.2019.05.006

Galangco, J. (2023). Path model of mathematics achievement in senior high school. *Journal of Research in Mathematics Education*, *12*(3), 246- 264. http://dx.doi.org/10.17583/redimat.12759

Golding, J., & Batiibwe, M. S. K. (2021). A Design Approach to Mathematics Teacher Educator Development in East Africa. *Journal of Research and Advances in Mathematics Education*, *6*(1), 1-16. https://doi.org/10.23917/jramathedu.v6i1.11898

Gonçalves, R., Costa, C., & Abreu, T. (2018). Computer Algebra Systems and Dynamic Geometry Software as beneficial tools in teaching and learning Linear Algebra. In *International Conference on Technology and Innovation in Learning, Teaching and Education* (pp. 343-356). Cham: Springer International Publishing. http://dx.doi.org/10.1007/978-3-030-20954-4_26

Gurmu, F., Tuge, C., & Hunde, A. B. (2024). Effects of GeoGebra-assisted instructional methods on students' conceptual understanding of geometry. *Cogent Education, 11*(1), 2379745. https://doi.org/10.1080/2331186X.2024.2379745

Hafeez, M. (2021). Impact of Teacher's Training on Interest and Academic Achievements of Students by Multiple Teaching Methods. Pedagogical Research, 6(3), em0102. https://doi.org/10.29333/pr/11088

Article DOI: https://doi.org/10.37284/eajes.7.4.2454

Haji, S. (2019). NCTM's principles and standards for developing conceptual understanding in mathematics. *Journal of Research in Mathematics Trends and Technology*, *1*(2), 52-60. https://doi.org/10.32734/jormtt.v1i2.2836

Haleem, A., Javaid, M., Qadri, M. A., & Suman, R. (2022). Understanding the role of digital technologies in education: A review. *Sustainable Operations and Computers*, *3*, 275- 285. https://doi.org/10.1016/j.susoc.2022.05.004

Hall, C., & Lundin, M. (2024). Technology in the classroom: Personal computers and learning outcomes in primary school. *Economics of Education Review*, *100*, 102536. https://doi.org/10.1016/j.econedurev.2024.102536

Handal, B., Campbell, C., Cavanagh, M., Petocz, P., & Kelly, N. (2013). Technological pedagogical content knowledge of secondary mathematics teachers. *Contemporary Issues in Technology and Teacher Education*, *13*(1), 22-40.

Henderson, M., Ryan, T., Boud, D., Dawson, P., Phillips, M., Molloy, E., & Mahoney, P. (2021). The usefulness of feedback. *Active Learning in Higher Education*, *22*(3), 229-243. https://doi.org/10.1177/1469787419872393

Hillmayr, D., Ziernwald, L., Reinhold, F., Hofer, S. I., & Reiss, K. M. (2020). The potential of digital tools to enhance mathematics and science learning in secondary schools: a context-specific meta-analysis. *Computers and Education*, *153*, 103897. https://doi.org/10.1016/j.compedu.2020.103897

Hohenwarter, M., & Jones, K. (2007). Ways of linking geometry and algebra: the case of GeoGebra. *Proceedings of the British Society for Research into Learning Mathematics*, *27*(3), 126-131.

Hohenwarter, M., & Fuchs, K. (2004). Combination of dynamic geometry, algebra, and calculus in the software system GeoGebra. In *Computer Algebra Systems and Dynamic Geometry Systems in Mathematics Teaching Conference* (Vol. 2002, pp. 1-6).

Joshi, D. R., & Singh, K. B. (2020). Effect of using GeoGebra on Eight Grade students' understanding in learning linear equations. *Mathematics Teaching Research Journal*, *12*(3), 76-83.

Jaelani, A., & Rahmah, D. (2019). Students' perceptions toward the use of mobile learning in learning English. *English Journal*, *13*(1), 9-18.

Jumaat, N. F., Tasir, Z., Halim, N. D. A., & Ashari, Z. M. (2017). Project-based learning from constructivism point of view. *Advanced Science Letters*, *23*(8), 7904-7906. http://dx.doi.org/10.1166/asl.2017.9605

Khalil, M., Sultana, N., & Khalil, U. (2017). Exploration of mathematical thinking and its development through GeoGebra. *Journal of Educational Research*, *20*(1), 83-99.

Kibirige, I. (2023). Primary teachers' challenges in implementing ICT in Science, Technology, Engineering, and Mathematics (STEM) in the post-pandemic era in Uganda. *Education Sciences*, *13*(4), 382. http://dx.doi.org/10.3390/educsci13040382

Kim, K. M., & Md-Ali, R. (2017). GeoGebra: Towards realizing 21st century learning in mathematics education. *Malaysian Journal of Learning and Instruction*, 93-115. https://pdfs.semanticscholar.org/9425/ea513936217d67d6f258adc049360cce588e.pdf

Kebede, W. (2023). Investigating female learners' attitude and challenges towards mathematics at the Department of Mathematics, Injibara College of Teachers' Education, Injibara, Ethiopia. *Cogent Education*, *10*(2), 2256202. https://doi.org/10.1080/2331186X.2023.2256202

Kober N. (2015). Reaching Students: What Research Says About Effective Instruction in Undergraduate Science and Engineering. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: National Academies Press.

Koima, J. (2024). School electrification and academic outcomes in rural Kenya. *Journal of*

Article DOI: https://doi.org/10.37284/eajes.7.4.2454

Development Economics, *166*, 103178. https://doi.org/10.1016/j.jdeveco.2023.103178

Kokko, A. K., & Hirsto, L. (2021). From physical spaces to learning environments: processes in which physical spaces are transformed into learning environments. *Learning Environments Research*, *24*(1), 71-85. https://link.springer.com/article/10.1007/s10984-020-09315-0

Koc, N., & Celik, B. (2015). The impact of number of students per teacher on student achievement. *Procedia-Social and Behavioral Sciences*, *177*, 65-70. http://dx.doi.org/10.1016/j.sbspro.2015.02.335

Machromah, I. U., Purnomo, M. E. R., & Sari, C. K. (2019). Learning calculus with GeoGebra at college. In Journal of Physics: Conference Series (Vol. 1180, No. 1, p. 012008). IOP Publishing. https://doi.org/10.1088/1742-6596/1180/1/012008.

Maharjan, M., Dahal, N., & Pant, B. P. (2022). ICTs into mathematical instructions for meaningful teaching and learning. *Advances in Mobile Learning Educational Research, 2 (2), 341-350*. http://dx.doi.org/10.25082/AMLER.2022.02.004

Makrakis, V. G. (2014). ICTs as transformative enabling tools in education for sustainable development. *ICT in Education in Global Context: Emerging Trends Report 2013-2014*, 101-115. http://dx.doi.org/10.1007/978-3-662-43927-2_7

Mokotjo, L. G., & Mokhele, M. L. (2021). Challenges of integrating GeoGebra in the teaching of mathematics in South African High Schools. *Universal Journal of Educational Research*, 9(5), 963 - 973. https://doi.org/10.13189/ujer.2021.090509

Mthethwa, M., Bayaga, A., Bossé, M. J., & Williams, D. (2020). GeoGebra for learning and teaching: A parallel investigation. *South African Journal of Education*, *40*(2), 1-12. https://doi.org/10.15700/saje.v40n2a1669

Mudaly, V., & Fletcher, T. (2019). The effectiveness of GeoGebra when teaching linear functions using the iPad. *Problems of Education in the 21st Century, 77*(1), 55-81.

Mukamba, E., & Makamure, C. (2020). Integration of GeoGebra in teaching and learning geometric transformations at Ordinary level in Zimbabwe. *Contemporary Mathematics and Science Education, 1*(1), 1-8. https://doi.org/10.30935/conmaths/8431

Mukhtar, M., El Islami, R. A. Z., Damanhuri, D., & Hamundu, F. M. (2021). Information and Communication Technologies to improve problem solving and self-efficacy: exploring geometry learning using Dynamic Mathematics Software GeoGebra. *International Journal of STEM Education for Sustainability*, *1*(1), 45-52. https://doi.org/10.53889/ijses.v1i1.4

Mulwa, E. C. (2015). Difficulties Encountered by Students in the Learning and Usage of Mathematical Terminology: A Critical Literature Review. *Journal of Education and Practice*, *6*(13), 27-37.

Munyaruhengeri, J. P. A., Umugiraneza, O., Ndagijimana, J. B., & Hakizimana, T. (2023). Potentials and limitations of GeoGebra in teaching and learning limits and continuity of functions at selected senior four Rwandan secondary schools. *Cogent Education, 10* (2), 2238469. https://doi.org/10.1080/2331186X.2023.2238469

Musa, M., Mamat, Y., & Ghazali, M. (2021). Teachers' status of GeoGebra use in the teaching of geometric transformation. *Turkish Journal of Computer and Mathematics Education, 12*(14), 4326-4332.

Muslim, N. E. I., Zakaria, M. I., & Fang, C. Y. (2023). A systematic review of GeoGebra in mathematics education. *International Journal of Academic Research in Progressive Education and Development*, *12*(3), 1192-1203. http://dx.doi.org/10.6007/IJARPED/v12-i3/19133

Muweesi, C., Lou, S., Nakonde, J., Jerome. K. S., Tomusange, R., & Sserwadda, L. (2021).

Article DOI: https://doi.org/10.37284/eajes.7.4.2454

Discourses in ICT integration: pedagogical orientations in selected city primary schools in Uganda. *Educational Research and Reviews, 16*(5), 172-180. http://dx.doi.org/10.5897/ERR2020.4103

Mwingirwa, I. M., & Miheso-O'Connor, M. K. (2016). Status of teachers' technology uptake and use of GeoGebra in teaching secondary school mathematics in Kenya. *International Journal of Research in Education and Science, 2*(2), 286-294.

Nakitto, M. H., Mirembe, D. P., Waako, C., Lubega, J., Kibukamusoke, M., & Nambogo, F. (2022). The Influences of Open Access of Online Health Information on Patient Compliance to Professional Healthcare Providers Prescription in Kasangati Town Council, Wakiso District Uganda. *Advances in Social Sciences Research Journal, 9*(8), 602-616. https://doi.org/10.14738/assrj.98.12711

Nordin, N., Zakaria, E., Mohamed, N. R. N., & Embi, M. A. (2010). Pedagogical Usability of the Geometer's Sketchpad (GSP) Digital Module in the Mathematics Teaching. *Turkish Online Journal of Educational Technology-TOJET*, *9*(4), 113-117.

Nyakito, C., Amimo, C., & Allida, V. B. (2021). Challenges of integrating information and communication technology in teaching among National Teachers' Colleges in Uganda. *East African Journal of Education and Social Sciences, 2*(3), 157-171. https://doi.org/10.46606/eajess2021v02i03.011

Ocal, M. F. (2017). The effect of GeoGebra on students' conceptual and procedural knowledge: the case of applications of derivative. *Higher Education Studies*; 7(2), 67-78. http://doi.org/10.5539/hes.v7n2p67

Ogbonnaya, U. I., & Mushipe. M. (2020). The efficacy of GeoGebra-assisted instruction on students' drawing and interpretations of linear functions. *International Journal of Learning, Teaching and Educational Research, 19(9), 1-14.* https://doi.org/10.26803/ijlter.19.9.1

Oranga, J., & Matere, A. (2023). Qualitative research: essence, types and advantages. *Open Access Library Journal, 10 (12), 1–9.* https://doi.org/10.4236/oalib.1111001

Oulmaati, K., Ezzahri, S., & Samadi, K. (2017). The use of ICT in the learning process among the students of History and Civilization at Abdelmalek Essaadi University, Morocco. *International Journal of Scientific Research and Engineering Technology (IJSET),* 8 (2), 972-979.

Owusu, R., Bonyah. E., & Arthur, Y. D. (2023). The effect of GeoGebra on university students' understanding of polar coordinates. *Cogent Education*, *10*(1), 1- 16. https://doi.org/10.1080/2331186X.2023.2177050

Pamungkas, M. D., Rahmawati, F., & Dinara, H. A. (2019). Integrating GeoGebra into space geometry in college. *Advances in Social Science, Education, and Humanities Research, 397*, 999-1006.

Pandey, B. D. (2017). A study of mathematical achievement of secondary school students. *International Journal of Advanced Research, 5*(12), 1951-1954. http://dx.doi.org/10.21474/IJAR01/6165

Parland-von Essen, J., Fält, K., Maalick, Z., Alonen, M., & Gonzalez, E. (2018). Supporting FAIR data: categorization of research data as a tool in data management. *Informaatiotutkimus, 4*(37), 127-144. https://doi.org/10.23978/inf.77419

Puotier, Z., Ondigi, S. R., & Miheso-O'Connor, M. K. (2023). Pre-service teachers' perception of the use of GeoGebra in teaching and learning geometry in the colleges of education, Ghana: a systematic literature review. *Journal of Holistic Mathematics Education, 7*(1), 1-21. https://dx.doi.org/10.19166/johme.v7i1.6124

Rabi, F., Fengqi, M., Aziz, M., Ullah, M. I., & Abduraxmanovna, N. H. (2021). The impact of the use of GeoGebra on student's mathematical representation skills and attitude. *European Journal of Education Studies,* 8(2), 14-28. https://doi.org/10.46827/ejes.v8i12.4007

Article DOI: https://doi.org/10.37284/eajes.7.4.2454

Raja, R., & Nagasubramani, P. C. (2018). Impact of modern technology in education. *Journal of Applied and Advanced Research*, *3*(1), 33-35. http://dx.doi.org/10.21839/jaar.2018.v3iS1.165

Range, B. G., Duncan, H. E., Scherz, S. D., & Haines, C. A. (2012). School leaders' perceptions about incompetent teachers: Implications for supervision and evaluation. *NASSP Bulletin*, *96*(4), 302-322. http://dx.doi.org/10.1177/0192636512459554

Saha, R. A., Ayub, A. F. M., & Tarmizi, R. A. (2010). The effects of GeoGebra on mathematics achievement: enlightening coordinate geometry learning. *Procedia - Social and Behavioral Sciences*, 8, 686–693. https://doi.org/10.1016/j.sbspro.2010.12.095

Schwartz, R. M., Schmitt, M. C., & Lose, M. K. (2012). Effects of teacher-student ratio in response to intervention approaches. *The Elementary School Journal*, *112*(4), 547-567.

Shadaan, P., & Leong, K. E. (2022). Effectiveness of using GeoGebra on students' understanding in learning circles. *The Malaysian Online Journal of Educational Technology*, *1*(4), 1-11.

Simbolon, A. K. A. P., & Siahaan, L. M. (2020). The use of GeoGebra software in improving student's mathematical abilities in learning geometry. *In Proceedings of the International Conference on Culture Heritage, Education, Sustainable Tourism, and Innovation Technologie*s, (pp. 352-360). https://doi.org/10.5220/0010311800003051

Singh, L. K. (2018). Impact of using GeoGebra software on students' achievement in geometry: a study at secondary level. *Asian Resonance*, 7(5), 133–137.

Solheim, O. J., & Opheim, V. (2019). Beyond class size reduction: towards more flexible ways of implementing a reduced pupil-teacher ratio. *International Journal of Educational Research*, *96*, 146-153.

Srinivas, T. A. S., Srinvias, S., Donald, D., Sameena, M., Rekha, K., & Srihith, I. V. (2023). Unlocking the power of Matlab: A comprehensive survey. *International Journal of Advances in Research, Science, and Communication Technology*, *3*(1) 20-31. DOI: https://doi.org/10.48175/IJARSCT-9005

Tachie, S. A. (2019). Challenges and opportunities regarding usage of computers in the teaching and learning of mathematics. *South African Journal of Education*, *39*(2), 1-10. https://doi.org/10.15700/saje.v39ns2a1690

Tamam, B., & Dasari, D. (2021). The use of GeoGebra software in teaching mathematics. In *Journal of Physics: Conference Series* (Vol. 1882, No. 1, p. 012042). IOP Publishing. https://iopscience.iop.org/article/10.1088/1742-6596/1882/1/012042

Tajudin, N. M. (2013). Graphing Calculator and Geometer's Sketchpad in teaching and learning of mathematics. *Journal of Arts and Humanities (JAH)*, *2*(11), 53-66.

Thapa, R., Dahal, N., & Pant, B. P. (2022). GeoGebra integration in high school mathematics: an experiential exploration on concepts of circle. *Mathematics Teaching Research Journal*, *14*(5), 16-33.

Ubi, E. E., Odiong, A. U., & Igiri, O. I. (2018). Geometry viewed as a difficult mathematics. *International Journal of Innovative Science and Research Technology*, *3*(11), 251-255.

United Nations Educational, Scientific and Cultural Organization (UNESCO) (2021). Closing the Gap - Ensuring there are enough qualified and supported teachers in sub-Saharan Africa. Paris: Author.

Utami, C. T. P., Mardiyana, M., & Triyanto, T. (2019). Profile of students' mathematical representation ability in solving geometry problems. In *IOP Conference Series: Earth and Environmental Science*, *243* (1), p. 012123. IOP Publishing. http://dx.doi.org/10.1088/1755-1315/243/1/012123

Uwurukundo, M. S., Maniraho, J. F., & Rwibasira. M. T (2022a). Effect of GeoGebra software on secondary school students' achievement in 3-D geometry. *Education and Information*

Article DOI: https://doi.org/10.37284/eajes.7.4.2454

Technologies, *27*(4), 5749-5765. https://link.springer.com/article/10.1007%2Fs10639-021-10852-1

Uwurukundo, M. S., Maniraho, J. F., & Tusiime, M. (2022b). Enhancing students' attitudes in learning 3-Dimension geometry using GeoGebra. *International Journal of Learning, Teaching and Educational Research, 21*(6), 286-303. http://dx.doi.org/10.26803/ijlter.21.6.17

Vanderlinde, R., Aesaert, K. & van Braak, J. (2014). Institutionalised ICT use in primary education: a multilevel analysis. *Computers & Education, 72*, 1–10.

Velichova, D. (2011). Interactive maths with GeoGebra. *International Journal of Emerging Technologies in Learning (iJET), 6*(1), 31-35. https://doi.org/10.3991/ijet.v6iS1.1620

Verschaffel, L., Van Dooren, W., De Smedt, B. (2012). Mathematical Learning. In: Seel, N.M. (eds) Encyclopedia of the Sciences of Learning. Springer, Boston, MA. https://doi.org/10.1007/978-1-4419-1428-6_448

Wang, J. S., Pascarella, E. T., Nelson Laird, T. F., & Ribera, A. K. (2015). How clear and organized classroom instruction and deep approaches to learning affect growth in critical thinking and need for cognition. *Studies in Higher Education*, *40*(10), 1786- 1807. http://dx.doi.org/10.1080/03075079.2014.914911

Wassie, Y. A., & Zergaw, G. A, (2019). Some of the potential affordances, challenges and limitations of using GeoGebra in mathematics education**.** *EURASIA Journal of Mathematics, Science and Technology Education, 15*(8), 1-11. https://doi.org/10.29333/ejmste/108436

Williams, M. E. (2017). An Examination of Technology Training Experiences from Teacher Candidacy to In-Service Professional Development. *Journal of Instructional Pedagogies*, *19*, 1-20.

Wills, W. M. (2022). Reviews and Documentary Research Methods in a Scientific Article. *International Journal of Research (IJR)*, *9*(9), 1-6.

Wright, M. C., Bergom, I., & Bartholomew, T. (2019). Decreased class size, increased active learning? Intended and enacted teaching strategies in smaller classes. *Active learning in higher education*, *20*(1), 51-62. https://doi.org/10.1177/1469787417735607

Yerizon. Y., Dwina, F., & Tajudin, N. M. (2021). Improving students' spatial ability with GeoGebra software. *Universal Journal of Educational Research*, 9(1), 129 - 135. https://doi.org/10.13189/ujer.2021.090114

Yildiz, H., & Gokcek, T. (2018). The development process of a mathematics teacher's technological pedagogical content knowledge. European Journal of Educational Research, 7(1), 9-29. https://doi.org/10.12973/eu-jer.7.1

Yilmaz, R., & Argun, Z. (2018). Role of Visualization in Mathematical Abstraction: The Case of Congruence Concept. *International Journal of Education in Mathematics, Science and Technology*, *6*(1), 41-57.

Zayed, N. M. (2016). The pros and cons of teaching a small-sized class. *International Journal of Education and Research*, *4*(11), 271-276.

Zengin, Y., Furkan, H., & Kutluca, T. (2012). The effect of dynamic mathematics software GeoGebra on student achievement in teaching of trigonometry. *Procedia-Social and Behavioral Sciences*, *31*, 183-187. http://dx.doi.org/10.1016/j.sbspro.2011.12.038

Zengin, Y., & Tatar, E. (2017). Integrating dynamic mathematics software into cooperative learning environments in mathematics. *Educational Technology & Society*, *20* (2), 74-88.

