Research in Educational Policy and Management

https://repamjournal.org

E-ISSN: 2691-0667

Volume: 5 Issue: 3 2023

pp. 41-57

Exploring High School Mathematics Teachers' Experiences of Professional Development in the Integration of GeoGebra

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Article Info
Received: June 30, 2023
Accepted: October 3, 2023
Published: December 24, 2023

10.46303/repam.2023.20

How to cite
Mokotjo, L. G. (2023). Exploring high school mathematics teachers' experiences of professional development in the integration of GeoGebra. *Research in Educational Policy and Management*, *5*(3), 41-57.
https://doi.org/10.46303/repam.2023.20

ABSTRACT

This study investigated how high school mathematics teachers in South Africa integrate GeoGebra, a free dynamic mathematics software program, into their teaching practices. The research explored teachers' perceptions of the training they received for the GeoGebra software, their ability to create and implement GeoGebra-based lessons, and their confidence in using it in the classroom. The study employed an interpretive research paradigm to gather insights through unstructured interviews with four purposefully selected teachers from South Africa's Northwest Province. Despite the absence of a structured training program, the study findings indicate teachers' enthusiasm for adopting GeoGebra. The study underscores the need for the Department of Basic Education to enhance support to address potential obstacles and the importance of aligning GeoGebra training with existing guidelines for integrating information and communication technologies within the Department of Basic Education and school management. In summary, this study provides valuable insights into how professional development impacts high school mathematics teachers' incorporation of GeoGebra, with implications for the design and implementation of future programs aimed at helping teachers integrate technology into their instructional practices.

KEYWORDS
Information communication integration; GeoGebra; professional development; mathematics; technology.

INTRODUCTION

The South African e-Education policy and Professional Development Framework for Digital Learning were implemented in schools to usher in change and provide a structured approach to integrating technology into the learning environment. This framework was designed to enhance professional development for digital learning within an educational system that aspires to improve accessibility, quality, equity, redress, and efficiency (Department of Basic Education (DBE), 2019). The South African DBE introduced policies to reinforce teaching and learning by equipping teachers with information and communication technology (ICT) tools and enhancing their capacity to integrate these tools into their teaching practices effectively. Notably, some South African high school teachers have undergone training in integrating the GeoGebra mathematics software as one of these ICT tools. Rogers and Bannister (2016) posit a positive correlation between enhanced mathematics performance and the effective integration of GeoGebra in mathematics instruction.

The integration of ICT is heralded as a key solution for transforming mathematics education globally (Mendezabal & Tindowen, 2018). The use of technology in the mathematics classroom is known to heighten engagement between teachers and learners (Gemin, Pape, Vashaw & Watson, 2015), resulting in increased attention, motivation, concentration (Bester & Brand, 2013), and most importantly, improved learner performance (Engel & Green, 2011; Lan, 2018). Paradoxically, despite having access to and skills using ICT tools, teachers often struggle to effectively incorporate them into their teaching (Baytak et al., 2011; Govender & Govender, 2014; Kilinc et al., 2018; Tarman et al., 2019). Consequently, there is an urgent need to fortify teachers' professional development in technology integration, equipping them with the requisite knowledge and pedagogical skills to utilise technology effectively in their teaching (Gemin et al., 2015; Marais, 2023; Mlambo et al., 2023).

Furthermore, empirical data suggests that professional programs tailored to enhance teacher development have been effective in augmenting the competencies required for technology integration in the classroom (Liu, Tsai & Huang, 2015). Cheng, Lu, Xie and Vongkulluksn (2020) concur that evidence indicates that teachers exposed to high-quality professional development exhibit discernible improvements in their skills and abilities to employ technology. Therefore, the South African DBE reinforces the integration of ICT tools by introducing key policy documents, namely the White Paper on e-Education and the Guidelines for Teacher Training and Professional Development in ICT and Training. The e-Education policy is centred on providing technological tools at the national level to enhance education quality through ICT (Department of Education (DoE), 2004). The Guidelines for Teacher Training and Professional Development in ICT and Training underscores the principles guiding teacher development, emphasising the need for teacher development programs to provide situated or contextualised learning experiences, ongoing support, and responsiveness to new technologies to adapt to the evolving nature of technology.

Hennesy, Harrison and Wamakole (2010) assert that professional development should be subject-specific to be most effective. Within the context of a mathematics classroom, various technological tools, including mathematics software, serve distinct purposes. GeoGebra is a highly regarded mathematics software application used in teaching mathematics in both developed and developing countries (Azizul & Din, 2018; Sudihartinih & Purniati, 2019). Notably, South Africa has conducted extensive training sessions in various provinces, exposing teachers to GeoGebra. GeoGebra is widely employed in South African high schools, with GeoGebra is widely employed in South African high schools, with search indicating it is used in the KwaZulu-Natal, Limpopo, Gauteng, and Limpopo Provinces research indicating its usage in KwaZulu-Natal, Limpopo, Gauteng, and Limpopo Provinces (Bayaga, Mthethwa, Bosse & Williams, 2019; Chimuka, 2017). Research from these studies demonstrates that learners taught using GeoGebra tend to achieve better mathematics results than those not exposed to this software.

Xu (2017) and Marshall and Schwind (2018) contend that the teacher plays a central role in integrating ICT, including software such as GeoGebra, within the educational environment. Leask and Younie (2013) raise questions about the limited attention given to enhancing teachers' professional knowledge despite acknowledging teacher quality as a critical determinant of educational outcomes. Strategies to extend the benefits of individual excellence encompass professional learning communities in schools, communities of practice, and networks that enable broader knowledge sharing on the Internet (Twining, Raffaghelli & Albion, 2013). The neglect of teacher professional development in technology integration may render teachers hesitant to incorporate technology into their teaching practices, underscoring the need for technology integration to be accompanied by relevant professional development (United Nations Educational, Scientific and Cultural Organization (UNESCO), 2012).

Mofokeng and Mji (2010) contend that teachers often resist integrating technology into their teaching. Therefore, there is a pressing need for effective professional development programs to address teachers' reservations about adopting pedagogical strategies that include technological tools such as GeoGebra in their teaching practices. Many teachers lack the confidence and skills to incorporate technology effectively into their teaching. While teachers may be proficient in using technology for administrative tasks such as responding to emails and grading assessments, they may lack the expertise needed to seamlessly integrate technology into their pedagogical methods (Uche et al., 2016). As Uche et al. (2016) affirm, professional teacher development allows teachers to collaborate with their peers, acquire new skills, and gain knowledge pertinent to the 21st-century learning environment.

Problem Statement

The increasing attention to incorporating GeoGebra in mathematics education stems from its potential to enrich students' comprehension of mathematical concepts and elevate their motivation and engagement in learning. Nevertheless, the successful integration of GeoGebra in mathematics education heavily relies on teachers' proficiency and confidence in utilising this tool effectively within the classroom.

Hence, exploring the impact of professional development training on the capacity of high school mathematics educators to seamlessly integrate GeoGebra into their instructional practices is a significant focal point for research. Consequently, this investigates educators' perspectives concerning their training for GeoGebra application, their competence in devising and implementing GeoGebra-based lessons, and their self-assurance in using GeoGebra in the classroom.

Research Question

The study's research question was as follows:

- What is the impact of professional development training in integrating GeoGebra on high school mathematics teachers?

LITERATURE REVIEW

Integration of ICT into the Professional Development Policy

Professional development (PD) for teachers focusing on integrating GeoGebra and other ICT tools is crucial for equipping educators with the necessary skills and knowledge to incorporate technology effectively into the teaching and learning environment. A shortage of PD has been identified as a contributing factor to the delayed adoption of technology in schools (Konstantinos, Andreas & Karakiza, 2013). South Africa has an existing Professional Development Framework for Digital Learning (DoE, 2018) to enhance teachers' competencies in facilitating learning with digital tools and resources. This framework aligns with the Department of Basic Education's (DBE) Action Plan to 2019 (DBE, 2015) and the Integrated Strategic Planning Framework for Teacher Education and Development in South Africa 2011–2025 (ISPFTED) (DoE and Department of Higher Education and Training, 2011). These initiatives collectively endorse and commit to integrating digital technology into the school curriculum in South African educational institutions. The DBE Action Plan to 2019 (DBE, 2015) recognises the need to provide schools with essential technological infrastructure, create guidelines for school management support, offer guidance for teachers on technology integration, and supply hardware and software designed specifically for ICT integration into the school curriculum. The participants in this study were well-acquainted with various technological tools and utilised laptops provided by the South African DBE.

Furthermore, The White Paper on e-Education (DoE, 2004) serves as a guide for the DoE in integrating ICT into teaching and learning. It stipulates that ICT tools should be employed as versatile teaching and learning instruments and integrated into teachers' professional development, underscoring the necessity of developing ICT skills and knowledge to enhance the teaching environment. Concurrent support should be provided to teachers in their efforts to integrate technology. The ISPFTED (DoE & Department of Higher Education and Training, 2011) emphasises the importance of teacher awareness and pedagogical skills in enhancing education and underscores the need to establish professional learning communities to strengthen the

teaching profession. Accordingly, the guide for teacher training and professional development was established to structure and guide teacher development in e-learning. The guide delineates the technological skills, attitudes, and values teachers need to implement the curriculum effectively with technology. Moreover, it specifies that professional development in ICT should expose teachers to various technological tools relevant to their subject and instruct them on when and how to use these tools. Additionally, teachers should collaborate with their peers to enhance their skills and receive ongoing support to accommodate the evolving nature of ICT and pedagogical guidance to integrate ICT tools effectively (Hindle, 2007).

The Integration of GeoGebra Software in Teaching Mathematics in High Schools

Goos (2010) contends that teaching practices should encompass classroom interaction with ICT software and clarify the roles of both teachers and students in this interaction. For example, when GeoGebra is used to teach functions in Grade 10, teachers must carefully plan when to introduce GeoGebra features in the context of function learning. This kind of knowledge does not come naturally; therefore, teachers need to acquire expertise in GeoGebra and gain pedagogical skills to teach with it. Gemin et al. (2015) affirm the need to initiate a teacher development program that equips teachers with the knowledge and skills to use technology effectively in their teaching. According to Leask and Younie (2013), teacher professional development should address the multifaceted knowledge required for effective teaching and involve developing efficient knowledge management processes. GeoGebra has been identified as an ICT tool that effectively teaches mathematics. It is widely used in various countries, including South Africa. Hohenwarter and Preiner (2007) note that the Ministry of Education in Australia recommended the integration of GeoGebra into schools and universities as early as 2006. Florida Atlantic University has also adopted it in the United States for mathematics projects aimed at enhancing the teaching and learning of mathematics.

Venkataraman (2012) conducted a study in Singapore on developing geometric reasoning skills in secondary school mathematics using GeoGebra software. The study concluded that GeoGebra makes learning abstract mathematical concepts more meaningful and helps learners visualise related concepts. Barve and Barve (2012) support this by noting improved learner performance in mathematics when GeoGebra was used in the teaching and learning process. However, the benefits of GeoGebra can only be realised when teachers are well-equipped with knowledge of the software and the skills to use these integral technological tools (Goos, 2010). Welch (2012) stresses that professional development is only effective when it centres on the link between educators' skills and knowledge and student learning, emphasising the need to develop teachers' technological skills to enhance mathematics teaching through GeoGebra.

METHOD

Research Design

This article is a component of a broader study that employed a qualitative research approach to delve into teachers' practices concerning integrating GeoGebra in mathematics instruction. The data utilised in this article was derived from the more extensive research to explore teachers' perspectives and perceptions of professional development in GeoGebra integration within South African high schools. As outlined by Creswell (2014), qualitative research is an approach that seeks to examine and uncover the meanings that individuals or groups assign to a social phenomenon. This study aligns with the interpretive paradigm, which contends that the meanings attached to phenomena must be comprehended within the context of people's lives (Okeke & van Wyk, 2017). Therefore, teachers' experiences play a crucial role in elucidating the professional development of teachers in GeoGebra integration.

Participants

The study examined teachers' professional development experiences in integrating GeoGebra and employed the case study design explained by Punch (2011) as an empirical inquiry that probes experience within its real-life context. It explored the experiences and views of four purposively selected teachers from the Northwest Province in South Africa as the four cases for data collection in the study. The selected teachers received training in integrating GeoGebra and have, since then, started using GeoGebra in their mathematics teaching. These teachers' lived experiences using GeoGebra in their mathematics teaching were the basis from which the data for the research emerged. Through these teachers' lived experiences and views, the study gained insights into the professional development of teachers in integrating GeoGebra and how such information may be used in integrating other mathematics software (cf. Zakaria & Lee, 2012).

This section provides bibliographical data on the teachers who participated in the study, maintaining their confidentiality through pseudonyms. The four participants are introduced below, along with their qualifications and experience:

- Magwe (pseudonym): Magwe is an experienced high school teacher with six years of teaching mathematics, physical science, and technology to students from Grades 8 to 12. He holds a Bachelor of Science (BSc) degree in Computer Science and Electronics, a Postgraduate Diploma in Education, and a Postgraduate Certificate in Education (PGCE). Magwe has been utilising various ICT tools, including GeoGebra, for the past 18 months as part of his teaching methodology.
- Sebaya (pseudonym): With six years of teaching experience, Sebaya has taught mathematics, natural science, and technology to students ranging from Grades 8 to 12 across several provinces in South Africa. His educational qualifications include a Bachelor of Education (BEd) Honours degree, a PGCE in Natural Science and Mathematics, and a Bachelor of Commerce (B. Comm) Statistics degree. Sebaya has integrated various ICT tools into his teaching practices for over a year, including GeoGebra.

- Golenyane (pseudonym): Golenyane is a seasoned educator with nine years of experience teaching mathematics, natural science, and computer science. He holds a Bachelor of Science (BSc) degree in Computer Science and has achieved a PGCE qualification. Golenyane has been actively using GeoGebra and other ICT software tools in his teaching for six years, demonstrating a deep familiarity with technology-enhanced instruction.
- Maziya (pseudonym): Maziya boasts five years of teaching experience, primarily focusing on mathematics and physical science instruction for students in Grades 8, 10 and 12. His educational background includes a Bachelor of Education (BEd) degree in Science and Mathematics, a Bachelor of Education (BEd) Honours degree in Physical Science, and ongoing pursuit of a Master of Education (MEd) degree. Maziya has also been integrating various ICT tools, including GeoGebra, into his teaching practices for over a year, showcasing a commitment to enhancing his pedagogy through technology.

Additionally, direct quotations from these participants are incorporated within this section to substantiate and reinforce the study's findings.

Data Analysis

The data were collected using semi-structured interviews and document analysis. The study analysed the GeoGebra training manual and lesson plans for the document analysis. The data were analysed using content analysis for the unstructured interview data and thematic analysis for the document analysis. The recorded interviews were transcribed, coded and categorised into meaningful themes, mainly focusing on teachers using GeoGebra and receiving training to implement it in their mathematics teaching. All the participants were given informed consent forms, which they signed as part of their pledge to participate voluntarily in the research.

FINDINGS

This section presents the study findings that emerged from the data. These findings are presented through semi-structured interview data into the following themes:

- PD support for integrating GeoGebra;
- Continued PD support for integrating GeoGebra;
- The contribution of PD for integrating GeoGebra; and
- Management support for integrating GeoGebra.

Below are the discussions of the themes that emerged from the study:

The Professional Development Support in the Integration of GeoGebra

In South Africa, there is a Professional Development Framework for Digital Learning document aimed at building teachers' competencies in facilitating learning with digital tools and resources. Greer, Koran and White (2016) posit that the lack of training in integrating ICT is one of the problems teachers experience. There is a need for teachers to develop their pedagogical foundation when integrating technological tools into their classrooms. Therefore, the study sought to establish the PD available to participating teachers in integrating GeoGebra when

teaching mathematics in their schools. The participants unanimously shared similar sentiments that the training was too brief for them to learn enough about GeoGebra. Magwe mentioned that the training happened within an hour. The DoE sent someone from the district, and the official downloaded the software and briefly showed them how the software works:

The training? It happened so quickly. Just one day we were called at the principal's office. Myself and the other teacher who teaches maths. There was the guy from the department. I can't remember his name, but [he] was from the department. He told us that there is a mathematics software called GeoGebra, and it would help learners with maths. He had the software on a CD and downloaded it to our laptops. The training was quick … maybe an hour.

Based on Magwe's experience stated above, the facilitator from the DoE came prepared with the GeoGebra software to download. However, it appears that there was an issue with the time dedicated to training teachers on using GeoGebra. Golenyane shared the same view of the minimalistic training experience. Golenyane also recited a similar experience to that of Magwe concerning the GeoGebra training, stating that:

I can say I never received any training of GeoGebra. The guy from the Department of Education came. He showed us briefly how we can integrate GeoGebra. I can't call that training. It was too quick. But I could follow because I knew GeoGebra (Golenyane).

The study established that teachers were given GeoGebra software with minimal support and no relevant contact person when they experienced challenges, concurring with Jansen (2010) that there is a need to strengthen teacher-training policy in developing countries. Participants could not remember the officer from the DoE who offered them training for GeoGebra. They all referred to him as the "guy" who offered GeoGebra training. This is a strong indictment of the lack of a relationship and communication between the teachers and officials responsible for training them in integrating GeoGebra.

Continued PD Support in the Integration of GeoGebra

The South African Professional Development Framework provides that there should be consistent support awarded to teachers as part of their professional development in ICT integration, including pedagogic support (from subject advisers in particular), technical support and creating communities of practice (Hindle, 2007). Therefore, the study sought to establish the nature of the support awarded to teachers after their initial training. Magwe noted that:

The last time we saw the guy from the department is when he came to show us the software. No one has said anything (Magwe).

Based on Magwe's comment above, even though the training was minimalistic, they gained some knowledge of GeoGebra and were keen to use it in their teaching. However, he believed it would be beneficial for the training officer to come again since the initial training:

The challenges that I have, honestly, I wish that the guy could come back again. Yes, because though we did try to introduce some concepts of skills whatever, but I feel it was not enough.

We were looking at the laptop, all of us, so I wish he would come back for us to learn more things (Magwe).

Sebaya explained that there was no follow-up training on GeoGebra even though they had subsequently attended other ICT training sessions:

We have not seen him since that day.

Maziya also reiterated that the GeoGebra training they received was inadequate to integrate the software confidently into their mathematics teaching and that the training officer never returned after introducing the software. Maziya added that:

It will be nice if that guy who gave us GeoGebra can come again. Just show us what this can do… I don't like using it (GeoGebra) sometimes because I am not sure of what I want to do.

Magwe mentioned that the training happened within an hour. The DoE sent someone from the district, and the official downloaded the software and briefly showed them how the software works for just one hour:

The training? It happened so quickly. Just one day we were called at the principal's office.

From the above-narrated experiences, it is evident there is a need to strengthen the level of support necessary for the teachers. Due to the lack of support, Maziya was not confident using GeoGebra to teach mathematics. The study further enquired whether teachers at the schools could support one another and whether there was some collaboration in terms of the teachers offering support to each other.

The Contribution of Professional Development in the Integration of GeoGebra

According to Abuhmaid (2011), teacher training courses help teachers receptive to adopting technology faster while showing more enthusiastic teachers new ways of implementing ICT in their profession. Dlamini (2018) argues that while it is crucial to measure the contribution of professional development in pedagogical integration and student achievement, ICT professional development must also positively change teachers' beliefs and attitudes about ICT to integrate it into their teaching. For mathematics software such as GeoGebra, various attributes can provide a positive influence in a classroom. Therefore, the study sought to establish the teachers' views and the influence of GeoGebra since receiving their training. Golenyane explained how the introduction of GeoGebra influenced his teaching and explained that:

Calculate the gradient of the first line and the gradient and the coordinates, but there I just-, you know, click, and then it gives me a gradient. And then they would ask, 'now this is the gradient of this line, this is the gradient of this' (Golenyane).

Sebaya further explained that he changed how he teaches the concept of functions. He explained that he found GeoGebra essential in comparing different types of graphs as the learners could observe the changes. Venkataraman (2012) affirms that GeoGebra makes learning mathematics meaningful and relatable. Sebaya noticed that the learning environment changed and learners improved from the GeoGebra input:

GeoGebra is so good … like in terms of comparison, you need to compare graphs. It's easy to compare different types of graphs and learners are observing. I can see the change in learners; they understand … and that is what I like.

Maziya mentioned that he used GeoGebra to teach a variety of graphs, including straight-line graphs, number patterns and geometry of two-dimensional shapes:

You can teach a number of topics using GeoGebra, like geometry of straight lines, graphs, number patterns, counting, geometry of 2D shapes. There is a lot; it's just that I can't remember others.

Zilinskiene (2014) agrees with the positive influence of teaching after introducing GeoGebra. According to Zilinskiene (2014:74), examining from a perspective of the use of GeoGebra in mathematics classroom learning activities, there are three main activities to consider, namely "demonstration; exploration and modelling; and creation and experimental work." Therefore, the study sought to establish the kind of influence the teachers received since they received training in using GeoGebra. It was noted that participants had changed how they taught some aspects of functions and geometry in their mathematics teachings.

Limitations of the PD in the Integration of GeoGebra

Hismannoglu (2012) postulates that teacher development, which is focused on the training of teachers, specifically on how teachers can integrate ICT in teaching mathematics, is necessary. Participants mentioned that they had attended ICT training workshops. However, there was no workshop training relating to GeoGebra or other mathematics software to enhance the teaching of mathematics:

We sometime have ICT workshop. Like last week. I was not around and attended the training. But, there was no workshop training for GeoGebra. It was that one gentleman from the department who gave us the GeoGebra (Magwe).

Sebaya also shared a similar experience in that he believed that he only knew less than half of what he needed to know about GeoGebra:

I know less than 50% of what I can do with GeoGebra. If I can see myself being able to draw my own diagrams, any diagram, then I would say that I am satisfied.

From the above interview, it is evident that the teachers were not confident in their knowledge of GeoGebra and, therefore, seldom used it. They could link teaching geometry to GeoGebra with the proper knowledge. UNESCO (2012) attests that the lack of attention to the PD of teachers in integrating technology renders them reluctant to use technology in their teaching. Therefore, there is a need for technology integration to be accompanied by relevant PD.

Management Support in the Integration of GeoGebra

ICT alone does not translate to success in the taught subjects. Tay et al. (2017) outline commitment and school culture as essential factors in facilitating the integration of ICT in the teaching and learning environment. According to Kannan et al. (2012), school leadership, especially school principals, should be able to use the technology themselves and support

teachers. Management support is vital in setting up the quality of training teachers receive. The study participants confirmed receiving inferior training in GeoGebra from the school principal's office through the arrangement with the school principal.

Sebaya noted that the GeoGebra training that he received was unplanned and lasted a couple of minutes in the principal's office:

Hey, we were busy that day, we were busy, and I don't remember whether it was a meeting or what, but it was very busy, and the principal was like, 'Just go to him for a few minutes, and then he just gave us pointers there and there'. So it wasn't really a training; we didn't do much. We just sat around the laptop, and the gentleman just went through the whole thing quickly (Sebaya).

Golenyane also had similar minimal training that occurred in the principal's office and said:

We received very little training in using GeoGebra. If we can have more training … The training happened in the principal's office (Golenyane).

Maziya shared the same sentiments on receiving training on the integration of GeoGebra software in the principal's office:

The department sent someone to train us for GeoGebra. It was one hour training at the principal's office. The trainer came, and we were called at the principal's office. We were told he has come to show us the software that will help in teaching mathematics. It was a quick thing. He showed us to click on a few pages. Input some equations. I'm not sure if I could call that training. Then left the information package that was downloaded on our laptops.

From the above quotation, it can be noted that the training in integrating GeoGebra was brief and weak, with no follow-up. However, also noted was the lack of management support if, indeed, the only training received was in the principal's office, and there was no intervention from management for comprehensive training. However, there is a need for further research to establish the involvement of management in the integration of GeoGebra.

The integration of GeoGebra in the teaching of mathematics involves other ICT tools. The study found that despite the lack of training on the integration of GeoGebra, there were various organisations which were keen to support teachers in its integration:

Sebaya also shared the professional support that was available to his school to assist them with the integration of technology in the teaching of mathematics and other subjects:

… there is this organization, Teach South African, and they once gave me a whole bunch of videos to facilitate the learners, to facilitate teaching. So, I have still kept them, and I have a number of the videos on my laptop (Sebaya).

Maziya also recounted the support that is available from other organisations that focus on offering assistance in teaching and learning, which includes the integration of ICT:

Yes, in President, Ramaphosa now. That says business people would want terms of the content delivery. There is support from area office, yes, and we also are a NECT school. That is

National Education Collaboration Trust. It's a Trust that was founded by the then deputy to help in the improvement of Mathematics and Physical sciences in schools, as well as English. So they visit schools, they take teachers, and they gather us material like question papers (Maziya).

From the above quotation excerpts, there is evidence that there was support available from private entities for schools to integrate technology into their learning environment, but there needs to be further engagement with such entities. However, there was a lack of support from the principal since participants indicated that the GeoGebra training happened in the principal's office. Based on the participants' views, the training only lasted a couple of hours, and there was no proper coherence or structure. The facilitator only showed the basic elements of GeoGebra. Participants indicated that there was support from other external organisations but lacked support from the school management.

DISCUSSION

The imperative for the effective integration of GeoGebra is a vital component of the intervention strategy to address the challenges of mathematics education in South African high schools. In contrast to South Africa, GeoGebra has already been successfully integrated into the mathematics curriculum of several high-performing countries. However, in South African high schools, the introduction of GeoGebra as a teaching and learning ICT tool is relatively recent. To truly enhance mathematics performance in South African high schools, teachers must possess the knowledge and pedagogical skills to utilise GeoGebra effectively. Consequently, the South African DoE has implemented policies designed to guide and initiate the professional development of teachers in integrating ICT tools, including GeoGebra.

Nevertheless, reliance solely on policies is inadequate. Hence, this research delved into the practical implementation of professional development programs to achieve effective GeoGebra integration. The proficient use of any technological tool fundamentally depends on educators themselves. A plethora of research endeavours have scrutinised the integration of GeoGebra in mathematics education, prompting the need to provide cognitive support to educators who may harbour self-perceived apprehensions about the software. This support represents a critical step toward its informed and sustainable use to enhance mathematics instruction and learning. Teacher training emerges as the cornerstone, motivating educators to incorporate various forms of technology into their teaching methodologies.

Within the scope of this study, it becomes evident that while teachers were provided with the GeoGebra software, they received minimal accompanying support. When they faced challenges or difficulties, they encountered a lack of readily available assistance, emphasising the need for enhanced teacher-training policies in developing nations.

Furthermore, the investigation exposed the inadequacy of the training provided, often consisting of brief sessions held in a principal's office, indicating a lack of strategic planning and school management support. These training sessions lacked depth and follow-up, revealing deficiencies in comprehensive training provision. This raises concerns about school

management's lack of intervention or support in recognising the need for more comprehensive training opportunities.

CONCLUSION

The study findings illustrate what happens when a mathematics software or ICT tool is introduced to teachers without proper structure and follow-up. The study further illuminates the distinction between the usage and the integration of mathematics software. In this study, teachers were given GeoGebra and a short demonstration of using the mathematics software. In this case, the teachers learnt about the usage of but lacked the pedagogical knowledge of using the software. Integrating GeoGebra in mathematics teaching would require teachers to be taught the knowledge and skills to use GeoGebra as a tool in class. The integration of GeoGebra means it is used in class as a teaching tool for demonstration, visualisation and assessment of various mathematics concepts. It is, therefore, crucial that the professional development in integrating GeoGebra puts teachers in a position where they have adequate knowledge of the software to use in their teaching.

Recommendations

The study puts forth several recommendations to enhance the integration of GeoGebra in mathematics education: Establishment of learning communities, further research on teacher competencies, alignment of professional training and development guidelines, and exploration of framework awareness and implementation. It is recommended that learning communities be established to facilitate collaboration among teachers. These communities should serve as platforms where educators can collaborate to plan lessons incorporating GeoGebra. This collaborative environment can also encourage teachers to share best practices and assist those encountering challenges with aspects of the software. Moreover, there is a clear need for additional research that delves deeper into teacher competencies concerning integrating GeoGebra in the mathematics classroom. A more comprehensive understanding of the skills and knowledge required for effective GeoGebra utilisation is essential in guiding professional development initiatives. The study further recommends aligning professional training and development guidelines. The study revealed a disconnect between the professional training received by teachers and the professional development guidelines designed to steer facilitators. Therefore, it is imperative to empower facilitators with the requisite skills and knowledge to effectively implement these guidelines for training teachers in integrating ICT tools, including GeoGebra software.

Future research endeavours should focus on exploring the awareness and implementation of the framework and other related policies. This exploration can provide valuable insights into the extent to which these policies are understood and applied in practice, offering opportunities for improvement and refinement. These recommendations aim to foster a more supportive and collaborative environment for teachers as they integrate GeoGebra into their teaching practices while addressing the disconnection between training and guideline

implementation. Moreover, future research efforts can contribute to a more informed and effective approach to policy implementation and teacher development in ICT integration.

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