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The Pedagogical Insights of Mathematics Teachers Integrating Artificial Intelligence in Rural Upper Primary Schools of Namibia

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Abstract: This paper presents a qualitative intervention study that explores the pedagogical experiences of mathematics teachers integrating Artificial Intelligence (AI) technologies into teaching mathematics in rural upper primary schools in Namibia. The Technological Pedagogical Content Knowledge (TPACK) framework, which intersects teachers' understanding of technology integration with pedagogical techniques and subject matter knowledge, was adopted for the study. The research involved 13 mathematics teachers selected through purposive sampling. Data collection included two sharing circle discussions, lesson observations, and semi-structured interviews. A thematic analysis approach was employed to interpret the collected data. The findings reveal a diverse range of AI tools used by the selected teachers, such as Geogebra, Khan Academy, Virtual Tutors, and various problem-solving mobile applications, including Photomath, Mathway, and Microsoft Math Solver. These AI resources were noted for enhancing the visualisation of mathematical concepts, providing adaptive learning experiences, and promoting independent, paced learning that supports learners' learning styles. Teachers reported a marked improvement in learners' comprehension and problem-solving abilities attributable to AI integration. Despite the benefits of AI in education, challenges remain, particularly in rural areas. Key issues include inadequate infrastructure, limited access to devices, and the need for ongoing teacher training in technological pedagogical content knowledge. Additionally, the lack of culturally relevant AI technologies hinders effective AI-supported learning in diverse contexts. Greater investment in localised AI educational tools is needed to achieve equitable and effective learning outcomes.

Keywords: Artificial intelligence, mathematics education, pedagogical practices, rural schools, technology integration.

1. Introduction

The development of Artificial Intelligence (AI) technologies and their application is spreading at an alarming rate, giving universal access to classroom spaces. The increase in AI technologies is greatly influencing the process of learning and teaching in schools. Some scholars define AI in different ways; for instance, bin Mohamed et al. (2022) define AI as the branch of computer science that concentrates on developing machines or systems capable of carrying out tasks that usually necessitate human intelligence, including learning, problem-solving, and decision-making. Njogu (2023, p. 5) views AI as "the ability of a computer or a robot controlled by a computer to do tasks that are usually done by humans because they require human intelligence and discernment." The integration of Artificial Intelligence as educational technology is affecting significant changes in the teaching of hard subjects such as mathematics (Tahiru, 2021; Vinayak, 2023), necessitating substantial changes in teaching methods, even in classrooms where teacher presence remains pivotal.

The 21st century has already expected an increase in AI in teaching, but COVID-19 has made it a reality. Some teachers in developing countries such as Namibia have experienced a transformation

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from traditional teaching methods to using various emerging technological tools and applications. One of the applications that is revolutionising the education sector is the use of AI applications as teaching tools. AI stands out as a transformative force, offering unique opportunities to revolutionise traditional pedagogical approaches in some developing countries (Pham & Sampson, 2022). In the context of rural primary schools in developing countries such as Namibia, where access to resources and educational technologies is limited, the integration of AI in teaching presents a unique opportunity to bridge gaps and cultivate a dynamic learning environment.

The Namibian Ministry of Education, Arts and Culture (MoEAC), through its Information Communication Technology (ICT) policy, expects all teachers to teach using digital technology and emerging technologies (MICT, 2009). Even though this ICT policy has been in place for the past 24 years, it does not provide a clear conceptual framework on how teachers should integrate these technologies into their subject teaching (Osakwe et al., 2017), and the gap still exists in incorporating technology into the teaching of hard subjects like mathematics.

Literature suggests that in developing countries such as Namibia, the incorporation of AI in teaching mathematics education may face challenges. While the availability of resources and infrastructure may be more limited compared to developed nations, there is still significant potential for AI technologies to positively impact mathematics teaching and learning in these contexts (Ahn & Edwin, 2018; Guerrero-Ortiz & BorromeoFerri, 2022). Scholars in the field of AI and mathematics suggest that while AI has the potential to enhance mathematics education, its effective use requires a thoughtful and strategic approach. Supriyadi and Kuncoro (2023) stress that with AI expected to revolutionise mathematics, teachers need to keep abreast of the latest tools used to teach and adapt to them while remaining committed to providing quality teaching. Vezetiu et al. (2021) further added that the implementation of AI in mathematics education requires careful consideration of pedagogical strategies and the selection of appropriate content.

With this recognition of the significance of employing AI as a teaching method for mathematics, the experiences of mathematics teachers have become crucial in the incorporation of AI in Namibia. Through these teachers’ encounters with teaching mathematics using AI, we ascertain the implementation of AI tools in schools and their ethical utilisation. The main emphasis of this study is on the teachers' pedagogical experiences of teaching mathematics with AI.

In light of the above, this qualitative study investigates the pedagogical insights of Namibian mathematics teachers from rural upper primary schools within the Oshana Education Circuit as they utilise AI technologies. Understanding teachers’ pedagogical experiences in integrating AI technologies is crucial, as these factors significantly influence their willingness and approach to incorporating such technologies into their teaching practices. Therefore, this study aims to enhance understanding and reveal the deeper experiences of rural mathematics teachers as they teach with AI technologies in under-resourced, rural upper primary schools. The study specifically focuses on the research question: *What are the rural mathematics teachers’ pedagogical insights in using Artificial Intelligence technologies in teaching mathematics in upper primary schools?* To thoroughly address this question, the authors begin by reviewing relevant literature before presenting the conceptual framework that guides their study. Following this, the research methodology and data collection procedures are explained. Subsequently, the paper presents the research findings and engages in a thoughtful discussion of their implications. Finally, it concludes by summarising the findings and offering recommendations for future research endeavours.

2. Review of Literature

The integration of Artificial Intelligence (AI) in mathematics education has been explored in various studies. Introducing AI into education goes beyond simply teaching teachers how to use it (Wardat et al., 2024). It also involves helping them understand how to effectively incorporate it into their teaching plans. For this to happen, teachers must first appreciate the value of educational technology and its potential to improve learning outcomes. According to Kutyniok (2023), there is a tremendous need for mathematics in the field of artificial intelligence. In the same vein, bin Mohamed et al. (2022) have stressed that mathematics educators and teachers should consider using innovative tools not typically seen in classrooms, such as robotics, in mathematics teaching as they work to support a focus on reasoning and sense-making and to make connections to children's community and cultural funds of knowledge. There is a positive predisposition towards the inclusion of robots in the learning and teaching of mathematical processes during the early years of schooling, even though some teachers claim there is a struggle to incorporate robots into their lessons due to the high number of students and limited space in their classrooms (Seckel et al., 2021). Zawacki-Richter et al. (2019) asserted that there exists a gap between AI and teachers' theoretical pedagogical perspectives. Additionally, educational scholars face challenges not only in acquiring computer programming skills but also in emulating human experts' intelligence when developing intelligent tutoring and adaptive learning systems (Hwang et al., 2020). While AI holds promise for enhancing students' learning outcomes, it poses persistent challenges for many educational researchers, teachers, and professionals. Kumari (2020, p. 2) argued that "We should not expect that AI will be the primary influence on mathematical learning. Instead, if teachers and students can fully explore the educational potentials of AI, it could enhance mathematical knowledge."

The adoption and integration of new technologies, such as AI, in the classroom, could elevate the standard of mathematics education and promote equality. Many scholars (Adiguzel et al., 2023; Orhani, 2021; Supriyadi & Kuncoro, 2023) have pointed out that conventional teaching methods in mathematics, such as recitation, dialogue, and discussion, have become ineffective, failing to inspire learners' enthusiasm and motivation for learning. Mallik (2018) emphasised that developing a single unified theory for learning mathematics is almost impossible due to the complexity and theoretical nature of the learning process. Understanding a mathematical concept hinges on forming a mental representation that accurately reflects its structure. Once learners grasp certain concepts, theorems, rules, and problem-solving skills, they should be able to independently tackle mathematical problems. AI plays a crucial role in helping students enhance both their mathematical and cognitive abilities throughout the learning process (Mallik, 2018).

Due to significant limitations in the implementation of modern teaching strategies, particularly those leveraging AI techniques, mathematics teachers have recognised, based on their experiences, the urgent necessity of integrating AI systems and applications into mathematics education. AI can serve various functions in this field, including acting as a learning companion or tutor, aiding teachers, providing learning support, and offering advisory assistance for policymaking in education (Chen & Chen, 2020; Grady et al., 2018; Hwang & Tu, 2021). Crowley (2015) and Fanchamps et al. (2021) suggested that by manipulating robotics, students can explore various mathematical concepts. The use of robotics in mathematics provides interactive feedback and helps students develop cognitive thinking and reasoning abilities. For example, Nguyen (2023) employed robots to assist children in learning multiplication and discovered that their mathematical achievement improved.

AI tools excel at recognising and solving computational problems (NCTM, 2024). Rather than posing a threat to mathematics instruction, some AI technologies create positive pressure to avoid the trap of shallow assessment, leading to assignments and assessments that integrate foundational skills with creative thinking. This pressure makes the need for experienced mathematics educators even more critical, not less. We argue that for mathematics teachers to effectively incorporate emerging technologies into 21st-century classrooms, several prerequisites must be fulfilled to ensure the successful integration of AI in mathematics education. These prerequisites include delineating the teacher's responsibilities, setting appropriate usage limits, and adjusting or refining traditional teaching approaches.

The research on the integration of AI in Namibian rural schools is still in its infancy, and there are few empirical studies and reports available in the public domain regarding the integration of technology in the education sector in the country. Notable examples include those of Castillo-Acobo et al. (2023) and Shipepe et al. (2021). According to the literature, this study will be the first attempt to explore the experiences of rural mathematics teachers in teaching mathematics with AI. Thus, the present study aims to bring to light new knowledge about the experiences of rural primary mathematics teachers who teach mathematics using AI.

3. Theoretical Framework

This research study is theoretically informed by the framework of Technological, Pedagogical, and Content Knowledge (TPACK). The TPACK framework builds on Shulman's (1986, 1987) conception of pedagogical content knowledge (PCK) by explicitly integrating the component of technological knowledge into the model. TPACK was initially presented as the precise intersection of three distinct knowledge constructs: technology, pedagogy, and subject matter content. The framework of PCK was then expanded beyond this intersection to encompass overlapping constructs of Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and PCK (Mishra & Koehler, 2006). Over time, the interplay between these constructs of TPACK has been reformulated as Technological Pedagogical Content Knowledge (TPACK). Putri et al. (2022) noted that TPACK is a beneficial conceptual framework for thinking about, examining, and evaluating the knowledge teachers need to possess to effectively incorporate technology into their classrooms. Willermark (2018) added that in the digital age, constructive teaching and learning must emphasise the complex interaction of content, pedagogy, and technological knowledge.

Mishra and Koehler (2006) introduced the TPACK framework as a means of describing the knowledge that teachers need to effectively integrate technology into their teaching practice while addressing the complex, multifaceted, and situated nature of teacher knowledge (see Figure 1). Ruthven (2014) observed that the TPACK framework draws attention to how new technological resources reshape teachers' pedagogical knowledge, content knowledge, and pedagogical content knowledge.

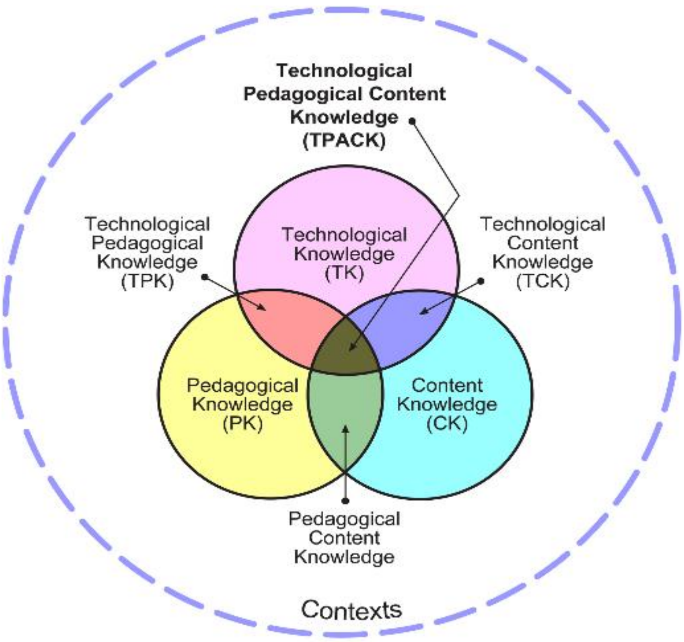

Figure 1: *The TPACK framework and its knowledge components (Koehler & Mishra, 2009).*

As indicated in the work of Koehler and Mishra (2009) Figure 1, the TPACK framework consists of seven constructs, as shown in Table 1 below.

Table 1: *The TPACK framework constructs*

The Constructs	Abbreviations	Definitions
Content Knowledge	CK	Knowledge of subject matter.
Technological Knowledge	TK	Knowledge of various technologies.
Pedagogical Knowledge	PK	Knowledge of the processes or methods of teaching.
Technological Content Knowledge	TCK	Knowledge of subject matter representation with technology.
Technological Pedagogical Knowledge	TPK	Knowledge of using technology to implement different teaching methods.
Pedagogical Content Knowledge	PCK	Knowledge of teaching methods for different types of subject matter.
Technological Pedagogical Content Knowledge	TPACK	Knowledge of using technology to implement teaching methods for different types of subject matter.

This study emphasises the TPACK framework as the primary lens for analysing teachers' experiences with the use and integration of AI tools in mathematics education. This choice is rooted in its congruence with the study's objectives and its potential to facilitate data generation to address the central research question. Utilising the TPACK framework enabled the authors to discern the interplay between pedagogical expertise (i.e., teaching methodologies) and technological proficiency (i.e., utilising technology, particularly AI), which are crucial aspects under investigation. Furthermore, the TPACK framework acknowledges that teaching with technology is context-dependent, prompting the consideration of various contextual factors, including school technology policies, the availability of technological infrastructure, and support from school administrators, which could influence teachers' experiences with AI-enabled teaching methodologies.

4. Methodology

Paradigm is used in educational research to describe a researcher's 'worldview' (Mackenzie & Knipe, 2006). This worldview represents the viewpoint, mindset, or ideological framework that shapes the understanding and interpretation of research data. This research study was situated within the interpretive paradigm, which asserts that there is no singular social reality that exists independently of the observer; rather, there are multiple socially constructed worlds (Willis, 2007). The participants in this study shared their insights, understandings, opinions, and interpretations of their own experiences regarding the intervention of using AI technologies in upper primary mathematics classes. The intervention involved the use of AI technologies chosen by the teachers to facilitate their teaching of mathematics. The study adopted an interpretive research philosophy to gain insights into the participants' meanings, thoughts, and views on integrating AI into mathematics pedagogy within their classrooms.

The choice of research design in this study was guided by a careful analysis of the problem statement, research questions, theoretical framework, and relevant literature (Asenahabi, 2019; Mwange et al., 2023). This study aimed to understand the subjective beliefs, views, and meanings reported by rural primary mathematics teachers regarding their pedagogical insights on using AI in teaching, making the qualitative research approach suitable for this investigation. The qualitative approach was employed to understand the meanings that participants ascribe to their experiences with AI in teaching mathematics (Goldkuhl, 2012; Willis, 2007). Additionally, the research was designed as an intervention study to investigate the impact of specific activities on teachers' practices (Muzari et al., 2022). The intervention involved a two-part approach: two workshops that introduced teachers to various freely accessible AI technologies applicable to education, followed by the independent implementation of chosen AI tools in their mathematics classrooms. This approach allowed teachers to personalise the integration of AI based on their teaching styles and students' needs. The purpose of this intervention design was to explore the real-world application and experiences of AI technologies in mathematics education through a teacher self-reported lens.

4.1 Participants of the study

The study purposively (Merriam, 2015) selected 13 rural upper primary mathematics teachers in the Hardap region, in particular the Kalahari Red Dunes cluster education circuit. The Kalahari Red Dunes cluster has five upper primary schools, and 13 mathematics teachers were selected from three rural upper primary schools. The three schools are equipped with technological infrastructure suitable for pedagogical purposes, such as computer laboratories, laptops, interactive whiteboards, and internet connectivity. Purposive sampling was chosen because we were interested in the pedagogical insights of teachers' integration of AI technologies in the choice of mathematics lessons in their classrooms. This aligns with our intervention research design, as we seek to understand the insights of this specific intervention on pedagogy in mathematics. By selecting participants with direct experience using the AIs, we were able to gather rich, contextualised data to inform study findings. Table 2 contains the participants' biographical data:

Teacher (Pseudonym)	Age	Qualification	Years of Experience
TR 1	24	Bed Mathematics & INSHE	5
TR 2	35	Bed Mathematics & English	9
TR 3	40	Bed Mathematics & English	17
TR 4	27	Bed Mathematics & INSHE	5
TR 5	33	Bed Mathematics & SOS	12
TR 6	24	Bed Mathematics & INSHE	4
TR 7	30	Bed Mathematics & SOS	9
TR 8	26	Bed Mathematics & INSHE	3
TR 9	26	Bed Mathematics & INSHE	5
TR 10	36	Bed Mathematics & English	14
TR 11	35	Bed Mathematics & English	15
TR 12	28	Bed Mathematics & INSHE	7
TR 13	29	Bed Mathematics & INSHE	7

4.2 Data collection tools

The utilisation of various data collection methods and sources enhances the reliability of the findings during data analysis. According to Yin (2014), data collection techniques encompass interviews, observations, and sharing circles. This qualitative intervention study employed two sharing circle discussions, lesson observations, and semi-structured interviews as data collection methods. The objective was to obtain a comprehensive understanding of teachers' pedagogical experiences regarding the integration of AI technologies in mathematics teaching. The study used two sharing circles to facilitate a collaborative and culturally responsive approach to data collection. Sharing circles provided a safe and structured space for teachers to share their experiences, perspectives, and cultural understandings related to the integration of AI in their classrooms (Simuja & Shikesho, 2024). We facilitated these sharing circles using open-ended questions and prompts to encourage dialogue and reflection among the participating teachers, and the conversations were audio-recorded. To ensure triangulation, consistency, and depth of information gathered, we used a semi-structured interview guide and a structured lesson observation guide to capture classroom practices.

4.3 Data analysis

Given the nature of our research, a thematic analysis approach (Clarke & Braun, 2017) was employed to analyse the qualitative data collected. This approach, as outlined by Braun and Clarke (2017), allowed us to identify, analyse, and report patterns within the data. Audio recordings from interviews and two sharing circles were transcribed verbatim, ensuring accuracy and completeness. The thematic analysis approach involved identifying, analysing, and reporting patterns (themes) within the data (Peel, 2022). The initial stage involved familiarisation with the data through repeated readings of the transcripts. Subsequently, initial codes were generated to capture significant ideas or concepts. These codes were then grouped into potential themes based on shared patterns and meanings. Themes were reviewed and refined through an iterative process, ensuring they accurately reflected the data. The identified themes are presented with supporting quotes from the transcripts to illustrate the findings. We employed inductive coding, allowing themes to emerge organically from the data rather than imposing a pre-determined framework. This systematic and rigorous approach to data analysis was deliberately adopted to ensure the trustworthiness and validity of the study's findings.

Ethical approval for this research was obtained from both the Provincial Department of Education and our affiliated university. Participation was voluntary, with the right to withdraw at any time. The study was conducted according to ethical guidelines, ensuring informed consent, confidentiality, anonymity, credibility, and trustworthiness.

5. Presentation of Results

In this section, the authors present the findings of this study regarding the teachers' pedagogical and technological experiences with the use of AI technologies for teaching mathematics. The emerging pedagogical insights from the teachers in this study reveal a variety of AI tools employed by the selected educators. These AI resources were noted for enhancing the visualisation of mathematical concepts, providing adaptive learning experiences, and promoting independent, self-paced learning. Teachers report a marked improvement in learners' comprehension and problem-solving abilities attributable to the integration of AI.

5.1 Findings from classroom observations

The data were collected from the lesson observations of the participants who took part in the study. During these observations, the researchers focused on the pedagogical insights of teachers when teaching mathematics using Artificial Intelligence. The lesson observation data addressed the main research question of this study, which examined how mathematics teachers integrate Artificial Intelligence (AI) into their teaching practices in rural upper primary schools in Namibia. Additionally, the observations explored the pedagogical approaches and strategies teachers employed when incorporating AI technologies into mathematics instruction. The aim was to gain insights into the effectiveness of AI integration in enhancing students' learning experiences and outcomes in mathematics education within the context of rural schools in Namibia.

In this study, we observed a variety of freely accessible AI technologies being used in primary school classrooms. Commonly adopted tools included Khan Academy for its prepared lesson content and virtual tutor features, as well as Geogebra for its dynamic visualisations of mathematical concepts. Additionally, teachers utilised several AI educational technologies and mathematics mobile apps such as Quizziz, Kahoot, Photomath, and Microsoft Math Solver. These readily available resources were incorporated into pedagogical practices to support learners' understanding and engagement with mathematics.

In observing the pedagogical approaches of upper primary mathematics teachers integrating AI, we noted how participants wove AI into the mathematics content through innovative instructional strategies. For instance, teachers utilised AI-powered adaptive learning platforms that modify exercises and quizzes to meet individual student needs, allowing for personalised learning paths. Furthermore, AI technologies were employed in classrooms to engage learners in hands-on exploration of complex mathematical concepts. During the lesson observations, the use of AI technologies not only enhanced conceptual understanding but also fostered a deeper engagement with the subject matter. The use of mobile applications such as Photomath and Symbolab increased learners' participation and motivation, leading to higher levels of student involvement in lesson activities. Additionally, teachers incorporated collaborative learning activities facilitated by AI technologies, which provided real-time feedback and encouraged peer interaction. This approach not only enriched classroom dynamics but also supported learners in developing critical thinking and problem-solving skills within the context of mathematics education.

5.2 Findings from sharing circle and interviews

The sharing circle discussions and semi-structured interviews provided rich insights into the pedagogical experiences of mathematics teachers integrating AI technologies into their classrooms. The study found that the most commonly adopted AI tools by teachers in Namibia were ChatGPT, Google Assistant, and Microsoft Math Solver. These tools were chosen for their ease of use, availability, and free access. Teachers reported using ChatGPT to generate creative writing prompts and lesson plans, Google Assistant for quick information searches and translations, and Microsoft Math Solver to assist students with complex mathematical concepts.

The participants demonstrated a significant shift in their pedagogical approaches due to the integration of AI. Teachers reported moving away from traditional, teacher-centred methods towards more learner-centred approaches. This shift was facilitated by the use of AI tools such as Geogebra, Khan Academy, and virtual tutors. These tools provided learners with personalised learning experiences, allowing them to learn at their own pace and receive targeted support. Participants T12 and T7 expressed this during the interviews:

> *…I have seen a real improvement in my students' understanding since we started using Khan Academy. They can work through the exercises at their own pace and get immediate… feedback (Participant T7)*

> *….Using Geogebra has made a big difference in how my learners understand geometry. They can now see the shapes and angles clearly, which helps them understand the concepts better… (Participant T7)*

Furthermore, the integration of AI fostered a more interactive and engaging learning environment. AI technologies facilitated game-based learning and simulations, making mathematics more enjoyable and accessible for learners. Teachers observed increased student motivation and engagement in mathematics lessons. For instance, T3 and T11 expressed their sentiments during the sharing circle:

> *…my learners love using Geogebra. They can visualize mathematical concepts and explore different scenarios in a fun and interactive way…*(Participant T11)

> *…The learners are more excited to come to Maths class now. They enjoy using the tablets and seeing the maths come alive with the visuals.* (Participant T3)

The participants also shared some interesting insights suggesting that AI promotes collaborative learning. Some AI technologies enabled learners to work together on mathematical tasks, share ideas, and support each other's learning. Teachers observed an increase in peer-to-peer learning and a stronger sense of community in their classrooms. Furthermore, the use of AI empowered teachers to cater to the diverse learning needs of their students. AI-powered assessment tools provide teachers with real-time data on student performance, allowing them to identify learning gaps and offer personalised support. T6 explained this during the sharing circle:

> *…the report I get from the Quizziz online helps me to change my instruction to meet the individual needs of my learners. I can see who is struggling and provide them with extra support…*

The findings suggest that AI has the potential to bridge the gap between traditional teaching methods and the evolving needs of 21st-century learners. By offering personalised learning experiences, fostering interactive learning environments, and empowering teachers with data-driven insights, AI is transforming the landscape of mathematics education in rural Namibian primary schools.

5.3 Challenges Encountered by Teachers' Integration of AI in Pedagogies

The participants in this study expressed that, despite positive experiences, some significant challenges were also noted. Most rural primary schools in the Kalahari Red Dune area have limited access to reliable internet connectivity, electricity, and appropriate technological support devices. This hinders the effective implementation of AI technologies in their classrooms. For instance, T6 stated during the sharing circle:

> *…..we often experience power outages, making it impossible to use AI-powered platforms during lessons consistently…*

Another challenge was the teachers' limited technological pedagogical content knowledge. Many teachers expressed a lack of confidence and skills in effectively integrating AI tools into their teaching practices. They struggled to align AI technologies with curriculum objectives and pedagogical approaches. Participant T5 shared during the interviews:

> *…I am not sure how to use these AI tools to teach specific mathematical concepts effectively. I need more training and support in this area…*

Furthermore, the study revealed that the lack of technical support and professional development opportunities for teachers posed a significant barrier to the successful integration of AI in mathematics education. Teachers highlighted the need for our research to offer ongoing training, mentorship, and technical assistance to enhance their skills and confidence in using AI tools effectively.

An interesting finding from this study was that the participants experienced limited availability of culturally relevant and localised AI technologies. Most AI educational resources were developed in contexts different from that of Namibian rural primary schools, making it difficult for the selected teachers to find materials that resonated with their learners' cultural backgrounds and learning needs. During the sharing circle, T8 commented:

> *…Many of the AI tools use examples and scenarios that our learners cannot relate to. It would be helpful to have resources that reflect our local languages, cultures, and contexts…*

T6 added:

> *The language barrier is a real issue. Most of the AI platforms are in English, and many of our learners are not proficient in English, making it difficult for them to benefit fully from these tools*."

While T11 explained:

> *…We need AI resources that incorporate our indigenous knowledge systems and relate to the realities of our learners' lives in rural areas…*

The comments from T8, T6, and T11 reveal significant barriers to AI integration in Namibian rural primary schools. These barriers include limited access to reliable infrastructure (such as electricity and internet), a lack of culturally relevant AI resources, and insufficient teacher training in AI technologies and their pedagogical applications. These challenges underscore the need for a multifaceted approach to successfully integrate AI into Namibian rural primary schools. Addressing these issues is crucial for the effective and equitable implementation of AI in mathematics education in these schools.

6. Discussion of Findings

The findings highlight a positive shift in pedagogical approaches, with teachers embracing AI tools to enhance their teaching practices. This aligns with studies from Shipepe et al. (2021) and Hwang and Tu (2021) that recognise the potential of AI to transform education, particularly in the education systems of developing countries. The study further identifies a range of AI technologies employed by teachers, including Geogebra, Khan Academy, and various problem-solving applications. These tools are noted for their ability to facilitate the visualisation of mathematical concepts, provide personalised learning experiences, and promote independent learning. This resonates with Egara and Mosimege’s (2024) study that emphasises the effectiveness of AI educational technologies in catering to diverse learning needs and promoting student engagement.

The study found that AI technologies facilitated the visualisation of complex mathematical concepts, promoting deeper understanding and engagement among learners. This suggests the efficacy of visual aids in mathematics education, particularly for abstract concepts. Furthermore, the adaptive learning capabilities of AI technologies, as highlighted by the teachers, catered to learners' needs, fostering independent learning at a personalised pace. This concurs with the principles of differentiated instruction, which have been shown to be effective in diverse learning environments (Hoyles, 2018; Supriyadi & Kuncoro, 2023). Moreover, the teachers observed the positive impact of AI integration on learners' mathematics comprehension and problem-solving abilities. This aligns with findings from other studies, such as those by Shin (2020) and Wardat et al. (2021), which demonstrated the effectiveness of AI tutoring technology in improving mathematics achievement in Korea and Iraq.

The study also sheds light on how AI fostered student engagement and motivation. Teachers noted that the interactive nature of AI tools, coupled with the instant feedback they provided, made learning more engaging for students. This finding is consistent with research highlighting the potential of technology to enhance student motivation and engagement (Al-Omari & Jabr, 2020; Simuja & Silvanus, 2023). Moreover, the study suggests that AI tools empower students to take ownership of their learning by providing them with the means to learn at their own pace and revisit concepts as needed. This resonates with the principles of student-centred learning and the importance of fostering learner autonomy (Hsu et al., 2021).

The study acknowledges the challenges inherent in integrating AI into teaching practices, particularly in rural primary schools in Namibia, and concurs with the findings by Simuja and Shikesho (2023). However, it also reveals several challenges encountered by teachers during the integration process. A significant concern was the lack of adequate infrastructure and resources, such as reliable internet connectivity and access to appropriate devices. This digital divide is a well-documented issue in many rural communities globally and poses a significant barrier to the effective integration of technology in education. Furthermore, teachers expressed concerns about their own technological pedagogical content knowledge, highlighting the need for ongoing professional development opportunities to enhance their skills and confidence in using AI tools effectively.

Similarly, the study reveals a scarcity of culturally relevant AI technologies. It found that most AI technologies used by Namibian mathematics teachers in primary schools were developed outside their context, making it difficult to find materials that resonate with learners' cultural backgrounds and needs. This finding supports prior research highlighting the importance of culturally situated learning. For instance, a study by Hoyles (2018) demonstrated that incorporating culturally relevant pedagogy, which values students' cultural backgrounds and experiences, significantly improved academic performance and engagement among learners. This study, therefore, suggests that the lack of localised AI technologies in the Namibian context presents a barrier to achieving equitable and effective AI-supported learning. This underscores the need for greater investment in developing and disseminating AI educational tools specifically designed for diverse cultural contexts, including those found in rural Namibia.

7. Conclusion and Recommendations

In conclusion, the study's findings reveal the potential of AI to bridge resource gaps and enhance educational outcomes in rural primary school mathematics education in developing countries. Teachers' adoption of AI tools like Geogebra, Khan Academy, and virtual tutors facilitated engaging and personalised learning experiences, leading to improved students' mathematics comprehension and problem-solving skills. This demonstrates the transformative potential of AI in mathematics education, particularly in rural schools. Further research is recommended to explore the long-term effects of AI integration on students' achievement. Investigating the scalability and sustainability of AI implementation in diverse educational contexts is crucial.

Based on the findings from this study, the authors suggest that a study should be carried out on key areas that advance teachers' understanding of how Artificial Intelligence (AI) can enhance pedagogical practices. Furthermore, the impact of AI tools on learners' outcomes over time needs to be researched to identify the most effective AI resources for different educational contexts. The authors also suggest that teacher training programmes should be developed to support teachers in effectively integrating AI technologies into their teaching. There is a need to explore the role of AI further in promoting learner engagement and motivation, addressing issues regarding AI integration in mathematics education. By addressing these areas, future research can inform evidence-based practices and policy decisions to maximise the benefits of AI in mathematics teaching and learning.

8. Declarations

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