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# Evolution of TPACK of rural primary school mathematics teachers through technology-integrated lesson design in Namibia

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## Abstract
Despite increasing access to digital technology, mathematics teachers in rural primary schools in Namibia face challenges integrating these tools effectively due to limited technological pedagogical content knowledge. With this study we explored how technology integration into lesson planning evolved TPACK development of these teachers. Eleven mathematics educators from rural primary schools in the Oshakati educational circuit were purposively selected to participate in a structured intervention comprising 5 workshops. The focus of the workshops was on educational technology, TPACK principles, and collaborative lesson design. Data collected through semi-structured interviews, focus group discussions, and lesson plan analyses were analysed using a systematic 5-step qualitative approach. The findings indicate that integrating technology into lesson planning enhanced teachers' familiarity with digital technology and the potential application thereof in mathematics education. This enabled educators to make informed decisions about appropriate technology selection and use and facilitated innovative pedagogical strategies aligned with curriculum objectives. The results demonstrate the centrality of reflective practice and lesson design in teacher development, suggesting that technology integration provides a platform for professional growth and the advancement of TPACK in rural primary schools. These findings contribute empirical evidence supporting technology-enhanced teacher development in developing countries, with implications for targeted policy and practice.

**Keywords:** developing country; mathematics education; mathematics teachers; primary school; technology integration

## Introduction
The ongoing development of digital technology has significantly impacted the work routines of many individuals (Shilongo, 2023), and more similar changes are expected in the education sector (Khan, Sarwar, Chen & Khan, 2022). Moreover, Mukuka and Alex (2025) argue that modern-day teachers are challenged with teaching a generation that grew up with digital devices and is comfortable using them. This indicates the importance of integrating technology into education (Falloon, 2020; Shambare & Simuja, 2022), particularly in mathematics education, where the adoption of technology in teaching and learning is increasingly crucial (Alabdulaziz, 2021; Ritter, 2012).

Pramesti and Retnawati (2019:2) note that "many learners in developing countries encounter difficulties when learning mathematics, as mathematics instruction should aim to promote concept understanding and critical thinking." In most developing countries in Africa, these challenges are particularly experienced due to various factors such as limited resources, large class sizes, and varying student backgrounds (Chirimbana, Nghipandulwa & Kamati, 2022; Luneta, 2024). For example, research shows that fewer than 40% of Namibian learners meet the minimum proficiency standards in mathematics by the end of primary education (Kanandjebo & Kapenda, 2024). Similarly, studies in other developing countries report that 60% or more of learners struggle with mathematical concepts due to a lack of contextualised teaching approaches and limited access to technology (Papadakis, Kalogiannakis & Zaranis, 2021; Pramesti & Retnawati, 2019).

Dlamini and Rafiki (2022) suggest that educators incorporate innovative and effective approaches to teach hard subjects such as mathematics. Similarly, other studies (Elifas & Simuja, 2024; Papadakis et al., 2021; Siew, 2018) indicate that technology can offer key instructional benefits for practical mathematics learning. This suggests that integrating technology in mathematics lessons may assist teachers in creating engaging and lively classes (Mhlongo, Mbatha, Ramatsetse & Dlamini, 2023), which may support students in overcoming learning barriers through practical experiences instead of simple rote learning (Shambare & Simuja, 2022).

Consequently, teachers teaching mathematics in primary schools are increasingly required to broaden their understanding and improve their technological knowledge and skills for effective integration of technology in their teaching (Dorouka, Papadakis & Kalogiannakis, 2020; Mukuka & Alex, 2025). Nevertheless, as recommended by Harris and Hofer (2011:219), "successful incorporation of educational technology into teaching requires proper planning that takes into account the alignment of curriculum requirements, effective teaching methods, and the advantages and limitations of technology." In a similar vein, Mishra and Koehler (2006) suggest that to successfully include technology in teaching, teachers, including mathematics teachers, should have unique understanding called technological pedagogical content knowledge (TPACK). This understanding stems from acknowledging the complex interplay of technology, subject matter and teaching methods.

Possession of such understanding allows teachers to formulate tailored instruction plans depending on the specific situation and context, thus making TPACK essential for successful technology integration in mathematics teaching. According to Mishra and Koehler (2008), having TPACK means understanding how technology could be used to augment existing knowledge or create fresh insights. This knowledge is born from understanding the complex linkages between technology, subject matter and teaching methods. Such knowledge lets educators devise specialised teaching plans based on each given circumstance. Thus, TPACK serves as the basis for effective technology-enhanced mathematics teaching. According to Mishra and Koehler (2006), mastery of TPACK involves knowing how technology can enhance existing subject and content knowledge. We presume that mathematics educators proficient in TPACK can significantly improve teaching and learning by taking full advantage of successful technology integration.

### Teaching and Learning of Mathematics in Rural Schools in Namibia

In Namibia, primary school learners often struggle with mathematics, which is considered one of the most challenging subjects (Hamukwaya & Haser, 2021; Shipepe, Uwu-Khaeb, De Villiers, Jormanainen & Sutinen, 2022). Moreover, the recently revised curriculum, which introduces mathematical concepts at earlier grades, has increased the complexity of teaching and learning mathematics in Namibian primary schools (Kanandjebo & Kapenda, 2024). Even though it is complex, the Namibian Department of Education requires learning mathematics as a core subject in Grades 4 to 12, deviating from the standard of the previous curriculum. To mitigate the elevated stress due to the new curriculum, the Ministry of Education has conducted workshops to equip teachers with effective pedagogical methods for teaching specific topics in the mathematics curriculum for Grades 4 to 12 (Hamukwaya & Haser, 2021).

While content-focused and pedagogical workshops have been introduced, research reveals the importance of effective instruction methods for learners to fully understand complex mathematical topics (Ausiku, 2022; Moses, Nghipandulwa & Abed, 2024). Dorouka et al. (2020) suggest the need for more educational tools in mathematics teaching, given the new curriculum in Namibia. Similarly, Onodipe, Keengwe and Cottrell-Yongye (2020) suggest that educators should innovate their teaching methods to incorporate technology. In response, the Namibian Ministry of Education and other organisations are offering access and implementing technological resources like computers, internet and computer laboratories in schools. They have introduced technology training initiatives such as Tech/NA, International Computer Driving License workshops, and digital skills training for education.

The first author, like other primary school mathematics teachers, attended these workshops and training sessions while others did not. Despite the importance of such initiatives, they seemed to suggest a focus solely on the use of technology by all teachers (Hamukwaya & Haser, 2021). Although many initiatives are being advanced in the provision of technological resources and training initiatives in all Namibian schools, the integration of technology into mathematics education remains inadequately conceptualised and operationalised (Kanandjebo & Kapenda, 2024). Most teacher professional development initiatives in Namibia predominantly focus on access to and use of technology (Kanandjebo & Kapenda, 2024), yet these initiatives insufficiently address the intersection of technology, pedagogy and content knowledge (Mishra & Koehler, 2008). However, simply having access to technology does not guarantee that teachers can effectively use it to improve student learning (Harris & Hofer, 2011; Siew, 2018).

Consequently, many Namibian mathematics teachers, despite access to technology, struggle to align these tools meaningfully with curriculum objectives and pedagogical strategies (Hamukwaya & Haser, 2021). This disjunction results in technology being underutilised or misused, undermining its potential affordances to enrich learning experiences and outcomes (Egara & Mosimege, 2024; Papadakis et al., 2021). Many educators resort to traditional teaching methods because technology is inaccessible, inappropriate or difficult to integrate effectively with mathematics content (Ndakolo, 2023), resulting in low affordances of technology to improve learning outcomes. Furthermore, the socio-educational context in Namibia, characterised by limited technical support, inconsistent internet access and resource disparities, reflects the challenges that teachers face (Hamukwaya & Haser, 2021; Sunde, 2024). These contextual constraints make generic technology training and workshops insufficient and necessitate an approach that supports mathematics teachers in primary schools in integrating understanding of how to connect technology with pedagogical methods and subject content tailored to specific teaching contexts (TPACK) (Harris & Hofer, 2011; Mishra & Koehler, 2008).

Despite the acknowledged importance of TPACK, a significant research gap remains in how rural primary mathematics teachers in Namibia develop this integrated knowledge through technology-enhanced lesson planning within their unique context. We argue that existing professional development efforts in Namibia tend to focus on technology skills without adequately addressing how teachers can strategically select and apply technology to support mathematical concepts and student learning. Moreover, although TPACK has been extensively studied in various contexts, a gap remains in understanding how rural primary mathematics teachers in Namibia, a developing country with unique educational challenges (Kanandjebo & Kapenda, 2024), develop and use TPACK in their lesson design. Considering the importance of aiding teachers in developing TPACK, we implemented a study with the objective of aiding rural primary school mathematics teachers in building their TPACK. Through the intervention, the intention was to acquire empirical and tangible evidence and understand the process through which these educators evolve their TPACK when creating lesson plans.

This intervention research is important because understanding Namibian teachers' TPACK development can inform targeted professional development programmes and policies that promote the effective use of technology in mathematics education. We aimed to answer the following research question: How does the integration of technology into lesson planning nurture the evolution of TPACK among rural primary school mathematics teachers in the Oshakati educational circuit in Namibia?

## Literature Review

### *Technology affordances in mathematics education in developing countries*

The integration of technology into mathematics education continues to present potential challenges for enhancing learning outcomes, particularly in developing countries. The affordances of technology has the potential to address some of the unique challenges faced by developing countries, such as limited resources and large class sizes (Hamukwaya & Haser, 2021). Technology provides access to a wider range of educational materials, enabling learners and teachers to overcome traditional resource constraints (Bitar & Davidovich, 2024). Bitar and Davidovich (2024) reveal the transformative potential of digital tools in reshaping pedagogical approaches in higher education. Shambare and Simuja (2022) also observed this practice in the use of virtual laboratories in science education in selected rural primary schools in South Africa. However, the real potential of technology in mathematics education lies not just in overcoming limitations but in fundamentally transforming the learning experience, paving the way for personalised education.

One key area of transformation is the potential for personalised learning experiences. Digital technology allows for adaptive learning platforms that may cater for individual learner needs, providing targeted support and remediation where necessary. This is particularly important in diverse classrooms where learners have varying levels of prior knowledge (Al-Hail, Zguir & Koç, 2024). Furthermore, technology facilitates interactive and engaging learning experiences through simulations, virtual manipulatives, and gamified content, making abstract mathematical concepts more accessible and relevant to students' lives. For example, teachers can create tailored instruction plans depending on the specific situation and context, thus making technology essential for successful mathematics teaching.

However, the successful integration of technology in mathematics education requires more than just access to technology. Teachers need to develop TPACK (Mishra & Koehler, 2008), which encompasses an understanding of how technology, pedagogy, and content knowledge intersect to create effective learning experiences. TPACK enables teachers to make informed decisions about which technology to use, how to use it effectively and how to integrate it into their existing curriculum.

### *The historical base of TPACK*

Over the years, the focus was on teachers' mastery of their subject matter due to the perception that knowledgeable teachers can significantly improve student learning. As a result, numerous studies were aimed at understanding the methods and strategies that teachers use. Shulman (1987:8), for instance, emphasises the importance of expertise in subject matter and introduced the idea of pedagogical content knowledge (PCK). According to Shulman, teachers' understanding involves at least seven areas: subject matter, teaching methods, curriculum, student and learning knowledge, educational environment, PCK, and understanding of educational principles, goals, and objectives. Essentially, PCK blends subject knowledge and teaching knowledge, factoring in the interplay between subject matter and instructional methods, which encompasses elements such as representations, misconceptions, and teaching knowledge (Mishra & Koehler, 2006).

Historically, traditional technologies have been employed by teachers in educational settings, yet Shulman (1987) did not incorporate a technology knowledge component into his PCK concept. Nevertheless, research in the 21st century has begun to stress the importance of technology in augmenting teachers' knowledge. This is evident from the work by researchers like Mishra and Koehler (2006, 2008), who underscore the relevance of technological knowledge in teaching. The swift advancement of digital technology necessitates the integration of technology in education and calls for teachers to adeptly incorporate technology in their teaching approaches. As technology becomes increasingly important and part of education, new models for its incorporation have been established. One such model, TPACK (formerly known as TPCK), was introduced by Mishra and Koehler in 2006 and has since turned into a central research area in studies related to the use of technology in education.

### *Development of TPACK among mathematics teachers*

The increase in methods to enhance teachers' TPACK has been noticeable for over a decade since its introduction (Agyei & Voogt, 2012; Bas & Senturk, 2018; Doukakis, Psaltidou, Stavraki, Adamopoulos, Tsiotakis & Stergou, 2010). However, only a few studies have looked into the use of interventions and mathematics education activities by in-service teachers. Njiku, Mutarutinya and Maniraho (2021), who focused on improving the TPACK of science and mathematics teachers through group learning, found that mathematics teachers were less successful than their peers in science. Particularly, many mathematics teachers struggled with completing tasks that required the application of technology for learning. In the same study found better technology integration skills were found among teachers who used the TPACK framework to design lessons. Lesson design has been significant in improving TPACK among pre-service teachers and it has gained more recognition in initial teacher education. Similarly, Nguyen, Bower and Stevenson (2022) also emphasise the role of collaborative and practical tasks in promoting the development of TPACK among pre-service teachers.

Several researchers have proposed specific strategies to support teachers in developing technological pedagogical and content knowledge, such as collaborative learning-by-design (Harris & Hofer, 2011), instructional systems design (Mishra & Koehler, 2008) and collaborative reflection-upon-practice (Mishra & Koehler, 2006). Likewise, Hernawati and Jailani (2019) studied the specific knowledge required by mathematics teachers for effective teaching using the TPACK framework. Dalal, Archambault and Shelton (2017) also employed the TPACK framework to investigate what influenced teachers to integrate technology into teaching. Their findings suggest that teachers' understanding of technology and institutional support have a decisive role in TPACK development. Voithofer, Nelson, Han and Caines (2019), however, found that factors such as teaching methods, curriculum design and institutional support have more extensive impacts on teachers' TPACK and technology integration. However, despite these efforts, primarily conducted in Western countries, teachers in many developing countries, such as Namibia, are not effectively integrating technology into mathematics instruction. This lack of integration reveals the need for initiatives that focus on enhancing teachers' TPACK, especially in lesson planning involving technology.

## Theoretical Framework

### *Technological Pedagogical Content Knowledge (TPACK)*

We adopted the TPACK framework (Mishra & Koehler, 2006) in the study. The TPACK framework includes seven domains representing teacher knowledge. These include content knowledge (CK), pedagogical knowledge (PK), technological knowledge (TK), pedagogical content knowledge (PCK), technological content knowledge (TCK), technological, pedagogical knowledge (TPK), and technological, pedagogical content knowledge (TPCK). Mishra and Koehler (2008) demonstrate each of these knowledge domains.

The TPACK framework is composed of three interrelated knowledge areas (TK, CK, PK). To integrate TPACK effectively, teachers must understand these domains and the context in which they are to be applied. In some instances, the subject matter (content) may dictate the choice of technology used in instruction. For example, advanced technology may significantly enhance teaching subjects like mathematics, which rely heavily on visual aids and graphic illustrations. Education presents an "ill-structured" entity, thus making a universal model for educational technology integration unfeasible. Due to the unique teaching methods and technology requirements of different subjects, it becomes vital for mathematics teachers to enhance their TPACK for lesson planning. The TPACK framework serves as a robust guide for incorporating technology into lesson preparation for primary school mathematics teachers, potentially augmenting the likelihood of optimal TPACK outcomes. Therefore, the TPACK framework was selected as the theoretical framework for this study.

The TPACK model helps clarify the intricate interplay of distinct types of teacher knowledge, particularly in primary mathematics instruction (Hamukwaya & Haser, 2021; Kafyulilo, Fisser, Pieters & Voogt, 2015; Lee & Kim, 2014). The role of context within the TPACK model is crucial yet often overlooked. Scholars interpret context differently. Aspects such as subject matter, student level, learners' backgrounds, and available technology can all define context. Also, the structure and attributes of the learning environment can shape context. Other considerations like the classroom setup, the school's resources, and external factors such as state and national standards may also define context. Understanding these variables may enhance our grasp of how TPACK is formed and adjusted to various teaching and learning situations (Nepembe & Simuja, 2023).

The TPACK theory was adopted to conceptualise teachers' lesson planning as a critical site for the enactment and development of their technological pedagogical content knowledge. Rather than focusing on the practical application of technology in the classroom, we used lesson design as a window into rural primary school mathematics teachers' understanding of how technology, pedagogy and content intersect and inform each other. We used TPACK as a lens to gain insight into the complex considerations that teachers make as they attempt to integrate technology in ways that are pedagogically sound and appropriate for mathematics subject matter.

## Methodology

We employed a qualitative case study approach (Creswell, 2012), which serves as a tool for gaining a deeper understanding or interpretation of particular phenomena within their natural context. The interpretivist paradigm (Thanh & Thanh, 2015) was chosen for its usefulness in describing and making sense of worldly phenomena to share meaning, and this aligned with our objective of describing and interpreting these phenomena.

We purposively selected 11 mathematics teachers from four public primary schools in the Oshakati education circuit in Namibia (see Table 1). Seven of these teachers (MT3, MT1, MT4, MT6, MT7, MT10, MT11) had more than 5 years of teaching experience, while the remaining four (MT2, MT5, MT8, MT9) had less than 5 years of teaching experience in primary mathematics in rural schools. It is also important to note that all the teachers participated in technology training of 2 weeks presented by the Education Ministry through the Oshakati education circuit in 2021. Prior to the start of the study, ethics approval was sought and obtained from the affiliated university (ethics approval number 2023-7001-7378). Informed consent forms were signed by all participants, ensuring their voluntary participation and awareness of the purpose and procedures of the study.

**Table 1** Characteristics of the study participants

| Participant | Gender | Teaching experience | Technology access |
|---|---|---|---|
| Mathematics Teacher (MT)1 | Male (M) | 12 | Yes |
| MT2 | M | 3 | Yes |
| MT3 | M | 7 | Yes |
| MT4 | Female (F) | 9 | Yes |
| MT5 | M | 4 | Yes |
| MT6 | F | 15 | Yes |
| MT7 | F | 18 | Yes |
| MT8 | M | 3 | Yes |
| MT9 | M | 2 | Yes |
| MT10 | M | 11 | Yes |
| MT11 | F | 17 | Yes |

### Data Collection Approach

The research reported on in this article was centred around an intervention with the objective of enhancing the technological pedagogical content knowledge of primary school mathematics teachers through technology-focused lesson planning. It included five workshops introducing special educational technology, highlighting TPACK principles, and guiding technology integration in planning lessons. We concentrated on the teachers' experiences in improving their TPACK. The initial intervention phase spanned 3 weeks. After this, individual semi-structured interviews and one focus group discussion were held to capture participants' experiences and perspectives. The interviews and discussions with all the participants were audio recorded to gain insight into the participants' progress with regard to TPACK. The interviews and group conversations were guided by Harris and Hofer's (2011) concepts and Mishra and Koehler's (2006) TPACK framework. We chose two methods to gather data to ensure thorough cross-verification and high data reliability. Through the focus group discussions, we collected and recorded observations and ideas on the integration of technology into lesson planning. We analysed three lesson plans for each teacher participant.

### Data Analysis Procedure

We used a five-step analysis (Salmona & Kaczynski, 2024) in this study. Initially, the data were comprehensively understood by extensively reading and examining interview transcriptions, lesson plans, and focus group discussion transcripts. After that, we established preliminary codes by labelling various ideas and concepts derived from the data, which were then organised into potential themes. The second author explored these themes and identified patterns and relationships. In the fourth stage, these themes were closely examined and fine-tuned to maintain consistency and an accurate representation of the data. In the final stage, the ultimate themes and sub-themes emerging from the data were defined and named. The second author explicated these themes and subthemes convincingly, providing examples from the data for each one for better understanding. The outcome was a set of themes encapsulating key findings and insights regarding the development of TPACK among primary mathematics teachers through technology-integrated lesson planning.

Furthermore, the participants approved their case descriptions and analyses by doing member checking, which confirmed the accuracy of interpretations. In this article we used in-depth, descriptive quotes from the participants, enhancing the credibility of the findings. These quotes allow readers to interact directly with the participants' responses and experiences.

## Findings from the Study

The findings from this study, as reflected by responses to the main research question are outlined below, enriched by quotes from participants collected during semi-structured interviews and focus group discussions. The findings are presented and discussed in detail below.

### Advance the State of Knowledge regarding Selecting and Integrating Technologies

Findings from the study reveal that the process of developing mathematics lesson plans incorporating technology proved instrumental in exposing participants to innovative uses of specific technologies in mathematics education in rural primary schools. This integration process enlightened teachers about particular technological devices conducive to mathematics teaching. Additionally, it enhanced the teachers' comprehension of the potential benefits and limitations of technology, empowering them to make informed choices about their application in the classroom setting.

Some participants noted that incorporating technology into lesson planning allowed them to become familiar with various technological tools and their potential use in primary school mathematics education. While the participants had substantial experience in teaching mathematics and access to common technology such as mobile phones and laptops, the focus group discussion (FGD) revealed that this study was the participants' first teacher development activity with a focus on developing mathematics lessons that included technology. This lack of prior experience integrating technology into lesson planning posed challenges in effectively harnessing specific technological tools. However, a comment by MT9 reflects their TK progression.

> *... I have expanded my technological knowledge; I am now planning to use interesting clips from TikTok and Facebook in my teaching activities. I will try to make my lessons more engaging ... before we came to attend the workshops my knowledge of employing technology in my lessons was not good.…* (MT9 FGD)

In the course of our research, we noted that teachers expressed a marked enhancement in their grasp of technology. During the interview, MT7 stated as follows:

> *Initially, I was worried about integrating technology into my teaching. However, with more practice and learning, there is no doubt my understanding has improved. I am now competent and able to select a few ICTs* [Information and Communication Technologies]*, and this will make me a great teacher soon at my school.…* (MT7 Interview)

During the focus group discussion, the mathematics teachers often exhibited emotional reactions, a trend associated with their self-reported limited understanding of technology before pursuing the profession. This limited TK prompted significant emotional responses when these teachers encountered the task of integrating technology into lesson planning. MT2 and MT8 expressed the following:

> *… It is always a challenging task when we try to incorporate technology in our mathematics lesson because of our limited understanding of these tools. The lack of knowledge often results in frustration and even fear, which I believe affects our teaching performance.…* (MT2 FGD)
>
> *... I felt quite anxious when planning my first lessons because I was not sure if I could adequately know technology to include in my lesson activities ...* (MT8 FGD).

### Developing the Knowledge to Balance the Integration of Technology and Content Appropriately

The study results reveal that all participants were able to understand effective integration of technology and content (TCK). MT4, however, highlighted challenges experienced due to prior limited familiarity with technology (TK), leading to struggles in pinpointing the ideal technology for mathematics instruction (TPK). For participant MT9, the collaborative development of technology-infused lesson plans was instrumental in enabling their understanding of effective links between technological knowledge and content knowledge (TCK). These assertions were also echoed by MT4:

> *... like trying to find my way in* [a] *big city, the technology was overwhelming at first ... I was not used with planning technology to use technology in class. Now, it allows me to consider the best technology that could afford the content that I want to teach. I think I know how to make the technology and the teaching to work together....* (MT 4)

In addition to balancing content and technology, some teachers reported occasionally experiencing limitations in technology choice for integration due to discrepancies between available technology in schools and desired approaches of content delivery. This often leads to lesson planning and curriculum development without any technology. For instance, MT6 highlighted an event where a fellow voiced dissatisfaction over teaching "3D [three-dimensional] shapes" due to a lack of apt resources:

> *… most of the time, the technological resources we have are not in line with our curriculum objectives. Let us say, for instance, when teaching 3D shapes, it becomes tough to locate tools or software that can help us effectively. Not only our resources are limited, but most technology available is irrelevant to the content we need to deliver, so we resort to traditional methods.…* (MT6 Interviews)

Similar sentiments were voiced due to a deficiency in TK or other technology-related limitations. These encapsulate the unavailability of technical assistance to troubleshoot technology-related problems and subpar internet access at schools.

### Gaining Knowledge on Effective Incorporation of Technology to Achieve Learning Outcomes

All the educators found the intervention valuable, as it provided insight on increasing teaching effectiveness through lesson activities planned to integrate technology. One of the teachers, MT3, expressed that the process of planning technology-integrated lessons increased their understanding of effective technology application in mathematics education. He intended to use two different technological devices that could offer the ability to demonstrate visual materials and another for implementing interactive assessment. Moreover, he articulated his desire to understand how to alternate between the two technologies to exhibit resources from both on the wide display.

The analysis of lesson plans shows an enhancement of mathematics teachers' understanding of the interplay between pedagogy, content and technology as a result of their participation in the intervention. Similarly, the teachers were able to bolster their TCK during the focus group discussions about their choices of technological tools to be used to share and present content. The intervention also shed light on how to go beyond using technology for transmitting information, thus aiding in the development of teachers' TPK. For instance, it was observed that MT1's lesson plans indicated his plan to implement learner-centred techniques and technology in the classroom. He chose to include Google Classroom and YouTube videos in the lesson activities, guided by his TPK and TK. Additionally, MT5's lesson plans suggested a push toward promoting learners' use of Facebook content during class. In the same vein MT7, MT2, and MT9 comment as follows:

> *I happy with this technology-integrated lesson planning workshop, we have got a chance to bring the lessons right to the learners. I am liking Kahoot! ... it is like a game, but I had an opportunity to learn that I can feed the tool with my lesson content when setting up this game, this will allow my learners to learn the right content. They will get to express themselves too.* (MT7 Interview)
>
> *We are not just going to use the technology to talk at the learners ... no, we want them to get in there with subject content, to use those cell phones for more than WhatsApp. We can learn plenty from these technologies for educational purposes, yeah.…* (MT2 Interview)
>
> *These things ... computers, phones, they are not just for show. They are real tools for teaching, they are. You use them right; they can make the learning something powerful ...* (MT9 Interview).

The lesson plans shared by the teachers suggest that the integration of technology in lessons was largely influenced by the overall rural primary schools and educational context, which encompasses factors like classroom conditions and school environment. These factors play a significant role in shaping teachers' understanding and use of technology, their pedagogical approaches, and the synergy between technology and these methods. The way in which these teachers combined technology, pedagogy, and content was greatly reliant on the context of application. Teachers highlighted the importance of understanding the contextual factors that affected the presentation of their instruction and learners' learning. This knowledge assisted them in making more informed decisions on how to effectively integrate technology into their lessons.

## Discussions and Conclusion

The findings of this study reveal the development of technological pedagogical content knowledge (TPACK) among selected rural primary school mathematics teachers through technology-integrated lesson planning. The integration process was instrumental in enhancing teachers' understanding of specific technological tools suited to mathematics teaching (TPK), as well as their ability to select appropriate technology aligned with curricular goals. For example, MT9's reflection on expanding their TK to include multimedia content from platforms such as TikTok and Facebook exemplifies this positive trajectory, illustrating how exposure to novel technology resources can broaden instructional possibilities. This concurs with prior research in which lesson design was identified as a pivotal factor in improving TPACK skills among pre-service teachers (Agyei & Voogt, 2012; Tyarakanita, Kurtianti & Fauziyati, 2020), confirming that active engagement in lesson creation stimulates meaningful technology engagement and pedagogical adaptation.

Furthermore, the study findings show the emotional and cognitive adjustments that the teachers experienced during technology integration. The initial anxiety and fear as a result of limited TK, as was expressed by MT2 and MT8, support findings from Doukakis et al. (2010) who note that novice teachers commonly face apprehension when confronted with the dual challenge of mastering both content and technology. Similarly, Huang, Huang and Lajoie (2022) observe that most teachers tended to develop a sense of competence and comfort as their understanding of TPACK deepened. However, over time, participants reported increased confidence and competence, suggesting that deliberate practice within supportive professional development contexts can mitigate these challenges. This trajectory supports Dalal et al.'s (2017) argument about the importance of sustained professional development in nurturing TPACK and informed decision-making concerning the use of technology.

Despite these affirming findings, we also noted that structural and contextual constraints shaped teachers' technological choices. Discrepancies between available resources and curriculum objectives restricted the seamless integration of technology for some participants. MT6's example of difficulty teaching 3D shapes due to inadequate technological resources resonates with concerns noted by Kanandjebo and Kapenda (2024), and Shilongo (2023), who argued that infrastructural limitations could impede the development of innovative pedagogical approaches despite teachers' willingness. This limitation suggests that while TPACK development can be supported through lesson planning initiatives, systemic factors such as resource allocation and school environment remain significant barriers.

In relation to pedagogical integration, the participants demonstrated an evolving understanding that technology should be embedded meaningfully rather than serving as an add-on or engagement tool. For instance, MT7 expressed the capability to "*feed the tool with lesson content*" during the development of a Kahoot! game – evidence of a purposeful alignment between technology and subject matter (TCK). The shift in using technology as a means to enhance pedagogical practices demonstrates growth in their TPK, a component of TPACK. This transition supports Koehler, Mishra and Cain's (2013) assertion that active reflection and practical engagement are key to TPACK development. Moreover, the varying degrees of familiarity and confidence reported by participants indicate that this deep pedagogical integration is not uniformly achieved, mirroring the caution expressed by Dorouka et al. (2020) regarding the uneven implementation of technology-infused science, technology, engineering, and mathematics (STEM) education in primary schools.

However, our findings contrast with others in the literature suggesting that a strong prior level of technology skills is essential for meaningful technology integration. In this study, teachers indicated that structured planning and collaborative reflection played a larger role in their growth than prior technological expertise. This challenges the view presented by Bezuidenhout (2021), who argues that limited technological skills serve as the main barrier to effective use. It reveals the importance of incorporating reflective practice and lesson design as central elements in teacher development initiatives.

The implications of this study demonstrate the necessity of understanding the broader educational context that influences the development of technological pedagogical content knowledge among teachers in developing countries. It signifies that technology integration and lesson planning processes are instrumental platforms for professional development in enhancing TPACK among primary school mathematics teachers. This research provides valuable empirical evidence on integrating technology into lesson planning, but further investigation is needed due to certain limitations. A key limitation was the small sample size of 11 mathematics teachers. The study results, although valuable, might not translate to larger groups due to this limitation. Thus, future research should consider larger sample sizes. We are also furthering the study to allow the selected rural primary school teachers to actualise their lesson plans. This would offer a more thorough evaluation of how the intervention programme affects teachers' TPACK application in mathematics education.

## Authors' Contributions

MA: Conceptualisation of the study, data collection, writing of the introduction and literature review. CS: Conceptualisation of the study, data analysis, writing of the methodologies, theory, findings, discussion of findings, and the conclusion.

## Notes

i. This article is based on the Masters in Education thesis of Mechtilde Angula.



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