Artículos

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UNDERSTANDING THE LANDSCAPE OF MATHEMATICS TEACHERS' PROFESSIONAL DEVELOPMENT IN SOUTH AFRICA

A REVIEW OF LITERATURE

COMPREENDENDO O PANORAMA DO DESENVOLVIMENTO PROFISSIONAL DE PROFESSORES DE MATEMÁTICA NA ÁFRICA DO SUL

Uma revisão da literatura

COMPRENDER EL PANORAMA DEL DESARROLLO PROFESIONAL DE LOS PROFESORES DE MATEMÁTICAS EN SUDÁFRICA

Una revisión de la literature

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ABSTRACT

Professional development is essential in standardizing the quality of mathematics teaching and enhancing meaningful learning experiences. This study systematically reviews the landscape of mathematics teachers' professional development in South Africa, focusing on training models, pedagogical content knowledge, indigenous knowledge systems integration, and challenges in implementation. A systematic literature review methodology was employed, involving a comprehensive search of peer-reviewed journal articles, policy documents, and government reports from academic databases such as Google Scholar, Scopus, Web of Science, and ERIC. Studies were selected based on relevance to mathematics teacher development and South African education policy, with thematic content analysis used to identify key trends and gaps in existing research. The findings reveal a persistent need for professional development programs that strengthen content knowledge, align pedagogy with curriculum reforms, and integrate indigenous knowledge systems. Additionally, the review highlights the role of technology as a transformative tool in mathematics education. However, limited access to quality professional development, insufficient teacher training resources, and the dominance of transmissive learning models remain significant barriers. The study concludes that targeted, contextually relevant professional development initiatives are necessary to improve mathematics instruction and student outcomes. Future research should focus on empirical comparisons of initial teacher education models and innovative strategies for integrating culturally responsive pedagogies into mathematics curricula.

Keywords: Mathematics teachers' professional development, Teacher training models, Indigenous knowledge systems, Curriculum development in mathematics education.

RESUMO

O desenvolvimento profissional é essencial para padronizar a qualidade do ensino de matemática e aprimorar experiências de aprendizagem significativas. Este estudo revisa sistematicamente o cenário do desenvolvimento profissional de professores de matemática na África do Sul, com foco em modelos de treinamento, conhecimento pedagógico do conteúdo, integração do conhecimento indígena e desafios na implementação. Foi empregada uma metodologia de revisão sistemática da literatura, envolvendo uma busca abrangente de artigos revisados por pares, documentos políticos e relatórios governamentais em bases de dados acadêmicas como Google Scholar, Scopus, Web of Science e ERIC. Os estudos foram selecionados com base na relevância para o desenvolvimento de professores de matemática e na política educacional sul-africana, utilizando a análise temática de conteúdo para identificar tendências-chave e lacunas na pesquisa existente. Os resultados revelam uma necessidade persistente de programas de desenvolvimento profissional que fortaleçam o conhecimento do conteúdo, alinhem a pedagogia às reformas curriculares e integrem sistemas de conhecimento indígena. Além disso, a revisão destaca o papel da tecnologia como uma ferramenta transformadora no ensino da matemática. No entanto, o acesso limitado a desenvolvimento profissional de qualidade, a insuficiência de recursos para a formação de professores e a predominância de modelos de ensino transmissivos continuam sendo barreiras significativas. O estudo conclui que iniciativas de desenvolvimento profissional direcionadas e contextualmente relevantes são necessárias para melhorar o ensino de matemática e os resultados dos alunos. Pesquisas futuras devem se concentrar em comparações empíricas de modelos de formação inicial de professores e em estratégias inovadoras para integrar pedagogias culturalmente responsivas nos currículos de matemática.

Palavras-chave: Desenvolvimento profissional de professores de matemática, Modelos de formação de professores, Sistemas de conhecimento indígena, Desenvolvimento curricular na educação matemática.

RESUMEN

El desarrollo profesional es esencial para estandarizar la calidad de la enseñanza de matemáticas y mejorar las experiencias de aprendizaje significativas. Este estudio revisa sistemáticamente el panorama del desarrollo profesional de los docentes de matemáticas en Sudáfrica, centrándose en modelos de formación, conocimientos pedagógicos del contenido, integración del conocimiento indígena y desafíos en la implementación. Se empleó una metodología de revisión sistemática de la literatura, que incluyó una búsqueda exhaustiva de artículos revisados por pares, documentos de políticas y reportes gubernamentales en bases de datos académicas como Google Scholar, Scopus, Web of Science y ERIC. Los estudios fueron seleccionados en función de su relevancia para el desarrollo de los docentes de matemáticas y la política educativa sudafricana, utilizando un análisis temático de contenido para identificar tendencias clave y brechas en la investigación existente. Los hallazgos revelan una necesidad persistente de programas de desarrollo profesional que fortalezcan el conocimiento del contenido, alineen la pedagogía con las reformas curriculares e integren sistemas de conocimiento indígena. Además, la revisión destaca el papel de la tecnología como una herramienta transformadora en la educación matemática. Sin embargo, el acceso limitado a un desarrollo profesional de calidad, la insuficiencia de recursos para la formación docente y la prevalencia de modelos de enseñanza transmisivos siguen siendo barreras significativas. El estudio concluye que se necesitan iniciativas de desarrollo profesional dirigidas y contextualmente relevantes para mejorar la enseñanza de las matemáticas y los resultados de los estudiantes. Las investigaciones futuras deben centrarse en comparaciones empíricas de los modelos de formación inicial docente y en estrategias innovadoras para integrar pedagogías culturalmente receptivas en los planes de estudio de matemáticas.

Palabras clave: Desarrollo profesional de docentes de matemáticas, Modelos de formación docente, Sistemas de conocimiento indígena, Desarrollo curricular en la educación matemática.

Introduction

The shortage of qualified mathematics teachers remains a pressing concern in South Africa, impacting student achievement and the overall quality of mathematics education. Mathematics plays a fundamental role in multiple disciplines, including science, technology, and engineering, and is essential for everyday problem-solving and economic participation (Gal et al., 2020; OECD, 2019, 2010; UNESCO, 2019). Despite its significance, mathematics education continues to face challenges, including low student enrolment and performance in the National Senior Certificate (NSC) examinations, insufficient enrolment in mathematics-related courses, and inadequate teacher preparation (Adler & Pillay, 2016; Chubb et al., 2012). These concerns necessitate a systematic examination of the professional development opportunities available to mathematics teachers and their effectiveness in enhancing instructional quality.

Over the past decades, numerous professional development initiatives have been introduced to improve mathematics instruction. These include government-driven reforms, institutional training programs, and international collaborations. However, challenges persist in ensuring the accessibility, relevance, and sustainability of these initiatives (Badmus & Jita, 2022; Badmus et al., 2023). Key issues include the effectiveness of teacher training models, the integration of indigenous knowledge systems (IKS) in mathematics education, and the role of technology in improving pedagogical practices (Adler, 2002; Adler & Davis, 2010; Carnoy et al., 2008). Addressing these concerns is crucial in aligning professional development with contemporary curriculum reforms and advancing the competencies of mathematics teachers in South Africa. This study aims to review systematically the landscape of mathematics teachers' professional development in South Africa. Specifically, it seeks to answer the following main research question: How do professional development initiatives impact mathematics teachers' pedagogical content knowledge, training models, and integration of indigenous knowledge systems in South Africa? By examining these questions, the study contributes to ongoing discussions on improving mathematics education through targeted and evidence-based professional development strategies. The findings will offer insights into existing gaps, inform policy recommendations, and suggest future research directions that can support the continuous professional growth of mathematics teachers.

Conceptual Framework

This study is grounded in Desimone's (2009) Core Conceptual Framework for Effective Professional Development, which provides a structured approach to evaluating the effectiveness of mathematics teacher professional development (MTPD). The framework identifies five essential components of high-quality PD: content focus, active learning, coherence, duration, and collective participation. These features serve as key indicators for assessing professional development initiatives and their impact on teacher learning, instructional practices, and ultimately, student achievement. Content Focus is central to effective PD, emphasizing the importance of subject-specific knowledge and pedagogical skills. Mathematics teacher PD is expected to target both deepening content knowledge and enhancing instructional strategies to improve classroom practice. Studies have consistently shown that PD programs with strong content focus led to better teaching effectiveness and higher student performance in mathematics. Active Learning refers to engagement in hands-on, practice-based experiences rather than passive participation in lecture-style workshops. Effective PD incorporates activities such as lesson planning, modelling instructional strategies, and collaborative reflection. Active engagement allows teachers to integrate new knowledge into their existing instructional practices more effectively.

Coherence relates to the alignment of PD with existing curricula, assessment policies, and teachers' daily instructional challenges. PD initiatives that are disconnected from teachers' classroom realities often fail

to produce lasting changes. Coherent PD programs reinforce ongoing learning by linking with broader school and district goals, providing a seamless connection between training and practical application.

Duration highlights the necessity of sustained engagement in PD over time. Short-term, one-off workshops are often insufficient in fostering meaningful improvements in teaching practices. Effective PD programs provide continuous learning opportunities, allowing teachers to apply, reflect, and refine their skills over extended periods. Research indicates that sustained PD participation is correlated with more significant instructional shifts and deeper conceptual understanding.

Collective Participation underscores the importance of collaboration among teachers within the same subject, school, or district. PD that encourages peer interactions, shared experiences, and professional learning communities (PLCs) fosters a supportive environment where teachers can exchange ideas, troubleshoot challenges, and develop best practices. Collective participation enhances professional growth by leveraging shared expertise and promoting a culture of continuous learning. By applying Desimone's (2009) framework, this study examines how MTPD initiatives in South Africa incorporate these five critical components. It also evaluates the extent to which PD programs align with teachers' needs, policy expectations, and curriculum reforms. Understanding the presence or absence of these features in current PD efforts provides insights into the challenges and opportunities for improving mathematics teacher professional development in the South African context.

Initial Mathematics Teacher Education

The first entry point to being a mathematics teacher is a university degree in any of the four phases of education [foundation, intermediate, senior and FET] in South Africa. This study concerns itself in the further education and training [FET] phase. Teacher quality is an established predictor of students' achievement (Deacon, 2012). Initial Teacher Education Research Project [ITERP] was conducted in 2014 to investigate across South African universities on how teachers are trained and the extent to which the training meets the need of the schooling system. The position of Bowie (2014) and Bowie and Reed (2016) on ITERP from five sampled universities showed that student teachers display low level of mathematics knowledge required for eventual classroom practice despite report of adequacy in mathematics preparatory courses undertaken. ITERP reported questionable quality in the initial mathematics teacher education from four out of five universities. Furthermore, the report of Council on Higher Education in 2010 described the state of initial teacher education as unhealthy, and Taylor (2018) reaffirmed this position in relation to mathematics. The direction of professional development is to in-service teachers of mathematics. However, improving initial mathematics teacher education programme is also important in addressing the inadequacy experienced.

Initial teacher education models in our context are concurrent and in other instance consecutive like many others across the world. The structure of these models is attributed as determinant of both quantity and quality of the teaching force (Alex & Robert, 2019; Musset, 2010). Concurrent model avail disciplinary courses and pedagogical courses all integrated and delivered at the time in the same institution for the period of training and certification. Consecutive model allows for teachers with disciplinary certification in pure or applied mathematics to engage in short learning programme such as postgraduate certificate in education [PGCE] build the pedagogical competence of such aspiring teacher for which a PGCE certificate is awarded (Zuzovsky & Donitsa-Schmidt, 2017). While there had been unofficial position on the effectiveness of either of these models in our context, the study of Zuzovsky and Donitsa-Schmidt (2017) provided a comparative position on the effectiveness of these two initial teacher education models benchmarking with efficiency and equity measures. Attrition was reported between the two models with the consecutive model having higher entry and superior retention rate of the two graduates from the initial teacher education programmes. This position is also supported by the study of Christophersen et al (2016) that teachers trained in consecutive model are exposed to more advanced content and compete with others in the content aspect of their courses. In south Africa, several universities run these models with non-empirical observations for and against the two models for now.

Concurrent model in our context for mathematics teachers dictates that pedagogy courses are offered in preservice teachers' home department at the faculty or school of education, while content courses are delivered in pure and applied mathematics departments with courses in this instance more advanced and not specifically tailored to the curriculum yet related to mathematics curriculum. In this instance, mathematics contents are offered by servicing department and have relevance to other fields and disciplines. In another instance of concurrent model, both pedagogy and mathematics courses are tailored to the curriculum mathematics teachers are expected to teach. Preservice teachers are directly taught and examined on how to teach each of the topics they will be teaching as professional teachers after graduation. The limitation with consecutive model is that trained teachers in this model may struggle with how to adapt their knowledge unlike the concurrent where practical approach on how to teach are already shown. From literature, teacher training programmes with consecutive models allow for deeper content knowledge and have higher retention rate for content knowledge unlike those from concurrent model. Scholars have reported lack or inadequate content knowledge among mathematics teacher both within and outside our context, hence a need to critically review these two models with a view to deepen content knowledge of mathematics teachers may form part of future research in our context.

Context of the Study

Table 1. NSC Achievement

	Mathematics Achievement			**Mathematical Literacy Achievement**		
Year	**% achieved at 30% and above**	**% achieved at 40% and above**	**% achieved at 50% and above**	**% achieved at 30% and above**	**% achieved at 40% and above**	**% achieved at 50% and above**
2015	49.1	31.9	20.3	71.4	44.3	25.1
2016	51.1	33.5	21.2	71.3	46.4	25.6
2017	51.9	35.1	22.2	73.9	45.0	23.7
2018	58.0	37.1	21.7	72.5	45.4	25.3
2019	54.6	35.0	20.3	80.6	54.5	32.2
2020	53.8	35.6	22.3	80.8	57.7	35.5
2021	57.6	37.6	23.0	74.5	49.1	29.4
2022	55.0	36.0	22.0	85.7	60.4	35.7
2023	63.5	43.6	27.5	82.3	56.7	33.5
2024	69.1	47.9	30.3	86.1	62.1	38.5

Source: Department of Basic Education Diagnostic Reports 2014-2023. X denotes unavailable data at the time of writing this manuscript.

Table 1 presents achievement of students in Matric examinations conducted between 2014-2023. From the table, performance at 30% achievement for mathematics remains average cumulatively as against mathematical literacy [ML] with satisfactory performance at the same achievement benchmark. Mathematical literacy [ML] was introduced to stem the knowledge of mathematics for everyday living.

As posited in the curriculum, ML's contents are limited to elementary/basic mathematical concept which involves sense making of both statistical and numerical scenarios for individuals to cope as critical citizens (making sense of real-life context). Furthermore, ML bridges the gap between mathematical content and real-life contexts (DBE, 2011). Worthy of note is the pattern of achievement at 50% benchmark, as reflected, students' achievement at this level remains unsatisfactory considering our educational and social needs. The implication of unsatisfactory performance in mathematics as earlier reported is economic, yet STEM (science, Technology, Engineering and Mathematics) field requiring better performance in mathematics continues to lag, leading to shortage of critical skills set, which has plagued the country for decades now. While the peculiarity within mathematics teacher training have been enumerated in the introductory section, worthy of attention, considering the focus of this study is the fact that curriculum reforms have since taken place with documented support to cater for evolving challenges in up-scaling pedagogical and content knowledge of MT.

Professional development effort for mathematics teachers is mainly to improve students' achievement, improve instruction, enhance content knowledge, align curriculum standards, integrate data driven approach to instruction as well as positive classroom for learning (Rosli & Aliwee, 2021; Sancar et al., 2021). Research so far is consistent in the provision of empirical data to support the need for PD, albeit, quality PD have only been reported to positively influence achievement. This research position inheres the need for tailored and qualitative PD for mathematics teachers if our expectations are to be achievable, and in any case, realistic. Aside QUANTUM, which was earlier discussed, additional PD for MT has been crucial area of attention to improve the quality of mathematics education going by the effort of South African Mathematics Foundation (SAMF) which aimed at enhancing MT pedagogical content knowledge (PCK), assessment methods and teaching strategies for alignment with the national curriculum as well as specific need of students and teacher (SAMF, 2019). Additionally, DBE in 2018 supported Mathematics Teachers Professionalisation [MTP] programme with South African higher institutions providing in-service training and continuous PD to MT. The focus was on promoting deeper knowledge and understanding of mathematical concepts, technology integration and effective teaching practice for better learning outcomes and student engagement (DBE, 2018). Furthermore, the University of Witwatersrand organised PD training for mathematics teachers on the need for creating community of practice among mathematics teachers. This effort was directed at developing and enhancing collaborative learning opportunities for MT to share resources, experiences, and best practices. It was observed that the initiative assisted in dealing with diverse challenges in mathematics teaching and promote professional growth (University of Witwatersrand, 2020). PD of mathematics teachers have always received attention from both private sector and the government of South Africa owing to the believe that education has the potential to mitigate inequality. This position paper contributes to developing discuss on professional development of mathematics teachers and a foundation for ongoing data collection and analysis effort of ETDP SETA at the University of the Free State. Particularly, one of the aims of the project is to generate a landscape review of the continuous PD of mathematics teachers.

Methodology

This literature review adopts a systematic approach to analysing the professional development landscape of mathematics teachers in South Africa. The methodology follows a structured framework that includes defining the research scope, selecting relevant literature, analysing key themes, and synthesizing findings to provide a comprehensive overview of the subject matter. We employ a qualitative research design, utilizing a literature review method to collect, analyse, and interpret existing studies on mathematics teachers' professional development. This approach ensures an in-depth examination of scholarly works, policy documents, and empirical research relevant to the South African context.

Data Collection

A comprehensive search of academic databases, government reports, and relevant policy documents was conducted to identify sources pertinent to the study. Key databases such as Google Scholar, Scopus,

Web of Science, and ERIC were used to retrieve peer-reviewed journal articles, books, and conference proceedings. Search terms included 'mathematics teacher professional development in South Africa,' 'teacher training models,' 'pedagogical content knowledge,' 'indigenous knowledge in mathematics education,' and 'technology integration in mathematics teaching.'

Inclusion and Exclusion Criteria

To ensure the relevance and quality of the literature, the following inclusion criteria were applied: Peer-reviewed journal articles, government reports, and policy documents published between 2000 and 2023. Studies focusing on professional development programs, instructional strategies, and curriculum reforms in mathematics education. Research conducted within the South African context or providing comparative insights applicable to South Africa. Studies were excluded if they: Focused on general teacher education without specific reference to mathematics. Were opinion pieces or lacked empirical evidence. Addressed professional development in contexts significantly different from South Africa's educational landscape.

Data Analysis

The downloaded literature was systematically analysed using thematic content analysis. Key themes such as professional development models, challenges in teacher training, integration of indigenous knowledge systems, and the role of technology in mathematics education were identified and categorized. Each study was examined for its objectives, methodologies, findings, and implications for mathematics teacher development.

Synthesis and Reporting

The findings were synthesized to provide an integrated perspective on the state of mathematics teachers' professional development in South Africa. The synthesis involved identifying patterns, drawing comparisons across different studies, and highlighting gaps in the existing literature. This structured approach ensures that the review offers a clear and well-supported narrative on the subject.

Ethical Consideration

Authors posit that ethical issues were not violated in this Manuscript. There are no direct human participants in this study, as such; no primary data were collected from respondents which may have required consent. The curriculum and policy documents employed in this study are public documents which require no authorization at the time of publishing this manuscript.

Literature Review

Here we review scholarly works outside our context to aggregate positions with a view to evolve practices of mathematics teachers through professional development efforts in our context. The report of OECD (2015) modelled the position of Hattie (2013) on positioning effective and collaborative professional development to teachers' practices with emphasis on the need to raise pertinent questions on outcomes evaluation in workplace with respect to the contribution of professional development to students' achievement. Mathematics teachers may be presented with a choice or otherwise to engage in professional development for the purpose of acquiring usable knowledge in their classrooms, get insight into how to apply specific curriculum, enhance their teaching techniques, earn college credit, among others. Vinnervik (2022) opined that the essence of Mathematics Teacher Professional Development [MTPD] may not only be to engage in PD activities to modify their attitudes or view, but more concerning is also the necessity to identify the relationships between the design of professional

development, the needs of specific mathematics teachers, and the actual outputs. To dissect this section, we first avail global literature on MTPD and later a contextualized review of literature within the South Africa context. Lastly, a synthesis of these two sub-sections is presented to the audience of this manuscript.

Global Perspectives on Mathematics Teacher Professional Development (MTPD)

Professional development (PD) plays a crucial role in enhancing teacher effectiveness when it is tailored to meet their diverse instructional needs (Darling-Hammond et al., 2009). In today's rapidly evolving educational landscape, PD has become a necessity due to continuous curriculum reforms, technological advancements, and the changing demands of modern classrooms. MTPD encompasses various domains, including instructional strategies, classroom management, student engagement, and content mastery, all of which contribute to improving mathematics teaching and learning outcomes. Research conducted in the United States highlights the challenges faced by mathematics teachers, including addressing the needs of students with learning difficulties, integrating technology, managing student behaviour, and improving content knowledge. These studies recommend additional PD programs to equip teachers with technological skills, behaviour management strategies, and effective classroom practices (Sancar et al., 2021). Similarly, Jacob et al. (2017) emphasize the importance of a deep understanding of content knowledge, pedagogy, and subject-specific competencies to effectively teach mathematical concepts such as quantities, measurements, numbers, and geometry. The study also underscores the need for MTPD focused on technology integration to enhance teacher competence in digitally supported instruction.

In Malaysia, Rosli and Aliwee (2021) argue that teacher needs and experiences should guide the design of PD programs to ensure their relevance and effectiveness. Their study highlights the importance of equipping teachers with diverse pedagogical tools to enhance instructional delivery. The findings suggest that structured training on effective teaching methods, lesson planning, and presentation skills should be prioritized. Furthermore, well-structured PD programs should incorporate time management strategies, extended training durations, and collaborative teacher engagement to maximize their impact.

A lack of adequate knowledge and skills regarding curriculum updates and adaptive teaching strategies presents a major barrier to effective instruction. Darling-Hammond (2017) posits that PD programs that consider teacher needs and priorities can significantly improve instructional practices. Karlberg and Bezzina (2022) further establish a positive correlation between teacher PD, instructional quality, and student learning outcomes, highlighting the transformative potential of continuous professional learning.

Targeted PD initiatives focusing on specific teaching topics have been found to shape teacher attitudes and instructional practices (Affouneh et al., 2020). According to these findings, mathematics teachers benefit from qualitative, skill-enhancing PD that refines their teaching methods and deepens their conceptual understanding. Additionally, Roschelle (2018) highlights how teacher participation in instructional PD directly improves student academic performance, reinforcing the need for high-impact PD models.

For PD initiatives to be truly effective, they must enhance both knowledge and instructional skills (Thurm & Barzel, 2020). Furthermore, mathematics teachers must continuously expand their expertise in curriculum innovation to ensure the success of PD programs (Penuel et al., 2007). Moving forward, global best practices should inform the development and implementation of structured, research-backed PD programs, ensuring that mathematics teachers are equipped with the necessary tools and strategies to navigate modern educational challenges successfully.

Mathematics Teacher Professional Development in South Africa

In South Africa, PD for mathematics teachers is critical for addressing the challenges posed by the country’s evolving educational landscape. The introduction of the Curriculum and Assessment Policy

Statement (CAPS) highlights the need for continuous PD to help teachers adapt to curriculum changes. However, research indicates that many PD initiatives in South Africa lack structured implementation and sustainability (Jojo, 2017). Studies have pointed out deficiencies in mathematics teachers' content knowledge, which often hinder their ability to effectively deliver lessons (Bansilal et al., 2014; Phoshoko, 2015). Research suggests that targeted interventions should focus on equipping teachers with both content knowledge and pedagogical strategies to address these gaps (Pournara et al., 2015).

Indigenous knowledge systems and decolonization literature

Since 1994, efforts have been directed in South Africa to preserve indigenous knowledge systems (IKS) as well as figure out how to connect the present content to contexts that are traditional and cultural. To foster a positive African identity, the Department of Science and Technology (2004) documented rationale to affirm African cultural values in the face of globalisation. Despite the afore stated, there is not much clarity provided as to how a teacher should include such knowledge in their mathematics curricula practices (Eyitayo, 2022; Jojo, 2017; Madimabe et al., 2022). The CAPS document for mathematics does not include the notion of IKS, however the CAPS documents for physical science and life sciences did make several allusions to IKS (Cindi, 2021). The document's silence on IKS is a subtle form of exclusion as it failed to emphasise the important of students using their social and cultural objects, customs, and beliefs of their indigenous communities to build their own knowledge (Matsekoleng et al., 2024; Meeran et al., 2022). It is obvious that the absence of IKS bricolage in the mathematics curriculum may point to the false notion that mathematics is pure and unaffected by external influence, such as cultural and social influences (Mudaly, 2018). Such epistemological innovation must also be demonstrated in mathematics teacher professional development by means of innovative search for and incorporation of various mathematics that incorporate multi-logicality [multiple valid knowledge sources] (Mudaly, 2018). Madimabe et al (2022) stated that there is shortage of cultural mathematics within the South African school system, the knowledge within the curriculum were not sufficiently localised to reflect the context for which it is meant to serve. The authors furthered that CAPS [DoE] documents demonstrate limited evident of authentic indigenous mathematics. Mathematics teachers should be equipped with training programmes that can help them decolonise the curriculum, as a large proportion of the mathematics curriculum is based on knowledge that emanates from Eurocentric contexts and is divided into specific topics like Euclidean geometry, calculus, and probability and more (Alex, 2019).

Content and pedagogical development literature

A crucial component of human resource development and management in mathematics education is teacher professional development. Part of the difficulty experienced is that there is still a knowledge gap regarding teachers' professional development, despite the department's best efforts to produce highly educated mathematics teachers. Teacher education is an area of professional education that aims to enhance teachers' professional classroom practices (Sancar et al., 2021). In a study by Jojo (2017), there are numerous well-publicised issues with South African education in particular. For most teachers and students in South Africa, mathematics is taught in English, which they speak as a second language. Instruction in English, which is a foreign language to both teachers and students, is provided from grades 4 through upper levels exclusively in school settings. Outside of the classroom, both parties return to their native tongues. Furthermore, difficulties in the classroom and at the level of government have been brought about by many modifications [OBE, curriculum 2005, NCS, and CAPS] made to mathematics syllabus and curriculum (Eyitayo, 2022).

Studies investigating the competence of mathematics teachers at various levels show that they lack sufficient knowledge of both mathematics content and pedagogical support that students need (Bansilal et al., 2014; Phoshoko, 2015). The inherent question may be- who ensures that teachers possess the necessary mathematical knowledge? Initial mathematics teacher education programmes should avail such knowledge, however, acclimatising to new knowledge areas resulting from changes in curriculum

content or new area of knowledge requires PD training. While separate section of this study will expose the models in initial mathematics education programmes, we argue that professionalisation is a continuing process especially for a fact that reforms are evolving, and the needs of the society also changes. The study of Phoshoko (2015) highlighted the need for PD of mathematics teachers as well as avail the primary sources of mathematics teachers' continuous professional development in South Africa with DBE, tertiary institution interventions, short courses, and non-governmental organisations as stakeholders. This provision is distinguished based on structure, style, and content that each stakeholder covers. Bansilal et al (2014) focused on a teacher's inadequate understanding of mathematics content.

The researchers posited that teacher's justifications were frequently irrational and incoherent to account for any meaningful learning. Few areas were pointed out to reflect teacher's inadequate comprehension, this includes ratio and number principles where the teacher gave students complex explanations including circular reasoning that were incomprehensible to students. Another researcher explored the connections between pedagogic content knowledge (PCK) and classroom practice in a calculus class in a different South African study by Delgado-Rebolledo & Zakaryan (2020). There was a clear correlation between PCK and classroom practice, according to the data. Scholars like Van Driel and Berry (2012) also concur that emphasis on content knowledge and pedagogical content knowledge should be part of professional development programmes for teachers in South Africa.

Technology integration literature

The integration of technology in mathematics education has been widely recognized as a transformative approach to improving teaching and learning. Studies indicate that technology-supported PD enhances teacher effectiveness by providing interactive and engaging instructional tools (Bishara, 2021; Abrahamson et al., 2020). Research further suggests that dynamic mathematics software, such as GeoGebra and Cabri, improves students' conceptual understanding and engagement (Stols & Kriek, 2011). Gamification is another emerging trend in mathematics education that has shown positive outcomes in student motivation and learning (Moloi et al., 2021). Indigenous games have been identified as effective tools for contextualizing mathematics instruction and making learning more engaging (Matsekoleng et al., 2024; Meeran et al., 2022). However, the successful implementation of gamification and technology in mathematics instruction requires well-structured PD programs that train teachers in effectively integrating these tools into their lessons (Thurm & Barzel, 2020).

Mathematical Practices and Knowledge systems

Prior to western form of education, numeracy has existed among our people with numbering, measuring of distance, counting, gamification of number among others in the knowing. Many of these forms of mathematical knowledge were culturally endemic and occasionally ethnic. The Curriculum and Assessment Policy Statement [CAPS] is a document of the DBE which guides the teaching, learning as well as assessment for all subjects including mathematics in the Republic of South Africa (DBE, 2011). The inclusion of ethnomathematics in the curriculum was not a coincidence in the decolonisation efforts through the acknowledgement and inclusion of diverse mathematical practices and knowledge systems (Mosimege, 2012; 2017). The uniqueness of cultural identity in mathematical knowledge is amplified to cater for national peculiarities. Diverse understanding of mathematics is recognised in the practice through decolonisation of mathematics education. For unfamiliar audience, the curious mind may ask what benefit might come from indigenous knowledge systems (IKS) as domesticated in mathematics curriculum. First point of sync is the cultural relevance that ethnomathematics allows for students to relate the knowledge of their heritage in their understanding of mathematics which helps to foster a sense of cultural identity (Bhuda & Pudi, 2020; Meeran et al., 2022). Through the incorporation of ethnomathematics, students are empowered to value their knowledge systems within the context of mathematics thereby contributing to a sense of inclusivity and equitable system of education.

In our context, gamification of mathematics is encouraged to assist in the decolonisation effort by making learning culturally relevant and engaging. According to literature, incorporation of indigenous games is with numerous advantages. The potential to guided learners in their problem-solving skills, provide culturally relevant learning experiences, improve connection to IK and advance conception of mathematical knowledge (Chahine et al., 2013; de F Afonso & Nhalevilo, 2013). Our previous position that mathematics is difficult is sustained, its teaching requiring quality skills acquirable through preservice training and continuous PD, equally important are scholarly concerns on engagement and motivation of students in mathematics classrooms (Adler, 2017; Adler & Pillay, 2016; McMeeking et al., 2012; Meeran et al., 2022). To sustain these two, more commitment is needed from mathematics teachers outside preservice training and even for in-service. Gamification in mathematics education have proven to be improve students' engagement and motivation (Bhuda & Pudi, 2020; Meeran et al., 2022). Even so, integration of culturally disjointed games in the classroom may be counterproductive. Upon this understanding, the mathematics curriculum in our context encourages the integration of indigenous game-based learning and interactive activities to make mathematics learning not only accessible but also enjoyable (DBE, 2011; Matsekoleng et al., 2024; Mosimege, 2017). This integration has proven to also promote critical thinking among students (Matsekoleng et al., 2024; Moloi et al., 2021). Globally, professional development is germane to quality outcomes for teacher, mathematics teachers are not immune to on-the-job training considering the difficulty experienced by students. PD along the curriculum specified approached should be prioritised to remediate unsatisfactory performance experienced.

Challenges of mathematics teachers PD

The benefits of professional development (PD) for mathematics teachers (MT) are numerous, and its continued relevance remains essential as societal demands evolve and influence curriculum reforms. Despite the opportunities that PD offers mathematics teachers, studies have highlighted several challenges, including limited access and insufficient time for participation (Rosli & Aliwee, 2021; Stol & Kriek, 2011). Another major issue is the dominance of transmissive models in professional learning, where facilitators insist on top-down approaches that do not adequately consider teachers' contexts (Penuel et al., 2007). These models lack the transformative essence of effective PD programs, unlike interactive approaches that encourage discussion and build on teachers' inherent skills.

Furthermore, implementing PD initiatives in mathematics classrooms is often frustrating due to a lack of resources and support. Teachers frequently train with specific educational resources, only to find that these materials are not readily available for classroom use. In many cases, the resources arrive long after the training, making knowledge transfer difficult, and ongoing support is often lacking.

Adapting to curriculum changes also poses a significant challenge for mathematics teachers, as PD programs are often conducted through quota-based selection and are hastily organized. The selected participants, who receive first-hand training, are expected to "step down" the training to their colleagues. However, by the time they conduct these sessions, conditions may have changed, and competencies may vary due to differences in experience with new methods or materials. Moreover, the selection criteria for these trainers are often flawed or unjustified, resulting in less effective step-down training.1

Discussion and Implications

The National Senior Certificate (NSC) diagnostic reports issued by the Department of Basic Education (DBE) provide critical insights into students' common errors and areas requiring instructional intervention. These reports highlight recurring misconceptions in mathematics, emphasizing the need for structured professional development (PD) that directly addresses these persistent challenges. However, while numerous PD initiatives have been implemented to enhance instructional quality, their effectiveness in bridging content knowledge gaps and improving pedagogical practices remains insufficient. Studies by Meeran et al. (2022), Taylor (2018), Pournara et al. (2015), Phoshoko (2015),

and Parker (2009) stress that PD should prioritize strengthening mathematics teachers' content knowledge to improve student outcomes. International research similarly underscores that content-specific PD, tailored to address instructional deficiencies, is crucial for effective mathematics instruction (Jacob et al., 2017; McMeeking et al., 2012; Van Driel & Berry, 2012; Telese, 2012).

According Desimone's (2009) Core Conceptual Framework for Effective PD, five critical components should be integrated into mathematics teacher PD programs in South Africa: Content Focus: Effective PD should emphasize subject-specific knowledge and pedagogical strategies. Research indicates that content knowledge deficits among South African mathematics teachers remain a barrier to quality instruction (Bansilal et al., 2014; Pournara et al., 2015). Future PD initiatives must incorporate Common Content Knowledge (CCK), Specialized Content Knowledge (SCK), and Horizon Content Knowledge (HCK) to equip teachers with a deep and practical understanding of mathematical concepts. Active Learning: Traditional transmissive models of PD often fail to produce meaningful instructional changes (Penuel et al., 2007). Instead, PD should integrate active learning strategies, such as collaborative problem-solving, lesson study, and microteaching, allowing teachers to apply and refine their instructional skills in real classroom settings (McMeeking et al., 2012). Coherence: For PD to be effective, it must align with existing curriculum frameworks, assessment policies, and national education goals (Desimone, 2009). South African mathematics teachers often struggle with curriculum adaptation due to misalignment between PD content and classroom realities. Therefore, PD programs must be designed to support curriculum implementation, policy reforms, and assessment alignment (Taylor, 2018; Phoshoko, 2015). Duration: Sustained and long-term engagement in PD has been shown to be more impactful than short-term workshops (Desimone, 2009; Van Driel & Berry, 2012). Many PD efforts in South Africa are brief and sporadic, limiting their impact on instructional change. Policymakers should invest in ongoing PD programs, mentorship initiatives, and professional learning communities (PLCs) to ensure continued teacher development (Badmus et al., 2023). Collective Participation: Collaborative PD that encourages teacher networks, mentorship, and peer learning fosters a supportive environment for instructional improvement (Thurm & Barzel, 2020). The development of subject-specific PLCs can enable mathematics teachers to share best practices, co-develop instructional materials, and engage in reflective teaching (Bishara, 2021).

Addressing Curriculum Decolonization and IKS Integration

The legacy of apartheid-era education continues to shape mathematics instruction in South Africa, necessitating efforts to decolonize the curriculum. Scholars argue for a transition from Eurocentric mathematics towards an Afrocentric framework that incorporates Indigenous Knowledge Systems (IKS) (Alex, 2019; Madimabe et al., 2022). Ethnomathematics and localized approaches to culturally relevant teaching have been identified as essential for increasing student engagement and conceptual understanding (Matsekoleng et al., 2024; Meeran et al., 2022). Despite these discussions, current mathematics curricula remain largely silent on IKS integration (Cindi, 2021). Future PD could provide teachers with structured guidance on embedding IKS and ethnomathematics into instructional practice while ensuring alignment with curriculum standards (Mosimege, 2012; 2017). This approach may foster students' cultural identity, enhance mathematical relevance, and address learning disparities (Bhuda & Pudi, 2020).

Leveraging Technology in Mathematics PD

The role of technology in mathematics education has gained significant attention in recent years. Research shows that technology integration enhances conceptual understanding and engagement (Abrahamson et al., 2020; Engelbrecht et al., 2020). PD programs should focus on equipping teachers with skills in using dynamic mathematics software, gamification techniques, and e-learning platforms (Stols & Kriek, 2011; Bishara, 2021). Although technology presents opportunities for instructional transformation, unstructured implementation and inadequate PD support have hindered effective adoption (Thurm & Barzel, 2020). Future PD should emphasize teacher training in digital pedagogies,

interactive learning strategies, and adaptive teaching technologies to optimize student learning experiences.

Going Forward

While existing PD initiatives for mathematics teachers have contributed to skill development, gaps remain in their ability to address persistent content deficiencies, curriculum decolonization, and technology integration. To improve mathematics education outcomes, PD efforts should be: Contextually relevant and aligned with teachers' needs. Sustained and interactive, avoiding short-term, lecture-based training. Inclusive of IKS, fostering culturally responsive teaching practices. Supportive of technology adoption, ensuring teachers receive hands-on training in digital tools. Future research should focus on empirical evaluations of PD models to determine their impact on student achievement, ensuring that mathematics teachers are adequately prepared to meet evolving educational demands.

Conclusion

This study examined the landscape of mathematics teacher professional development (MTPD) in South Africa, highlighting its role in addressing gaps in mathematics teaching and learning. The findings suggest that continuous MTPD is essential for improving instructional practices, particularly in enhancing teachers' content knowledge. However, the nature of the content knowledge required varies based on the frameworks and initial teacher education models that shape teachers' competencies.

Furthermore, while the integration of Indigenous Knowledge Systems (IKS) in mathematics education has been widely advocated, there is no unified approach to its implementation within the curriculum. Similarly, technology integration in mathematics instruction has demonstrated positive impacts, yet a more targeted approach—where digital tools are tailored to specific curriculum content and learning objectives—may yield better outcomes than generalized solutions. Addressing these challenges requires a more structured and context-responsive PD framework that considers the diverse needs of mathematics teachers, the evolving curriculum landscape, and the demand for innovative pedagogical strategies. Future research and policy efforts should focus on developing sustainable MTPD models that bridge existing gaps and foster more effective teaching and learning experiences.

Limitations of the Study

This study is limited to a systematic review of existing literature, which may not fully capture recent developments in professional development initiatives for mathematics teachers in South Africa. The analysis relies on secondary data, and the absence of empirical data collection restricts firsthand insights from teachers and stakeholders. Additionally, the study focuses primarily on the South African context, limiting the generalizability of findings to other regions. Variability in the quality of reviewed sources and potential publication bias may also impact the comprehensiveness of the conclusions drawn. Future studies could address these limitations by incorporating empirical research and comparative analyses across different educational contexts.

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