Informing Curriculum Design and Policy: Insights From Technology Integration in Circle Geometry Teaching at South African TVET Colleges

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Abstract

This qualitative study investigates the experiences and challenges of mathematics lecturers at a selected Technical and Vocational Education and Training (TVET) College in KwaZulu-Natal, South Africa, concerning their integration of technology in teaching Level 4 circle geometry. Utilizing an interpretive paradigm and a case study approach, data were collected through open-ended questionnaires and semi-structured interviews with five lecturers. Guided by the Technological Pedagogical and Content Knowledge (TPACK) framework, the research examined the methods and rationales behind lecturers' use of technology. Key findings indicate a notable deficit in relevant technological resources for teaching circle geometry within TVET Colleges, leading to significant pedagogical challenges for lecturers. While lecturers demonstrated proficiency in fundamental content, pedagogical, and technological knowledge (CK, PK, and TK), they often lacked the specialized competencies in Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and integrated TPACK essential for effective technology-enhanced geometry instruction. The study also highlighted disparities in technology access and the impact of students' foundational mathematical weaknesses on their geometry comprehension. These findings are crucial for informing curriculum planning and design initiatives by the Department of Higher Education and Training (DHET) and the Department of Basic Education (DBE) in South Africa. The research suggests that policies should be developed to facilitate access to appropriate technology and provide targeted professional development for mathematics lecturers, thereby enhancing the effectiveness of technology integration in the national mathematics education curriculum.

Keywords: circle geometry, curriculum design, mathematics education, technology integration, TVET colleges, policy recommendations, DHET

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Introduction

Mathematics is essential within the South African Technical and Vocational Education and Training (TVET) colleges because it prepares students and is a necessity for the future employment prospects (Adelabu & Pharamela, 2024). Despite this, research have placed in sharp perspective some of the typical problems of mathematics learning in such institutions, i.e., minimal conceptual understanding, poor teaching materials, and variable student preparedness.

Amongst the Level 4 mathematics syllabuses, circle geometry is 25% of the examination and is at the heart of students' geometric problem-solving ability, logical reasoning, and space appreciation. Knowledge of the principles of geometry of the circle—i.e., the interplay between angles, tangents, chords, and arcs—is the stepping stone on which more mathematical theory and application to architecture, engineering, and technical design are erected (Glaeser, 2020). Thus, successful understanding of circle geometry is of the highest priority to the realization of the advantages of the curriculum beyond enhancing the confidence and competence of students in mathematics.

Improvement of the quality of teaching mathematics over the last decade utilized the use of technology as a core strategy. Some examples of technology that have successfully facilitated learning interactions with abstract geometric ideas in an interactive and tangible fashion include interactive simulation, dynamic geometry software, and visualizations (İbili et al., 2020). The use of technology at large in TVET colleges would enable differentiated instruction, learner-centred pedagogies, and instant feedback, all of which assist in making sense and memorization of higher-level math concepts such as circle geometry easier (Ndlovu, 2023). In addition, this suggests that when embracing technology is in line with global trends in the education of STEM and prepares future workers for the technologically aligned work environments they will encounter.

This study focuses on assessing the effect of technology integration on the curriculum policy and planning of South African TVET colleges, with an emphasis on instruction of circle geometry at Level 4. Based on the consideration of pedagogical innovation, learner participation, and teaching approaches, this study presents evidence for teachers, curriculum planners, and policymakers to employ to improve the quality of mathematics teaching in the TVET sector. Despite recent improvements in pass rates, Mathematics in South Africa continues to face deep-rooted performance challenges (Department of Basic Education (DBE), 2025). The constant low performance of learners in matric results, achieving 40% reflects gaps in conceptual understanding and problem-solving skills. The widening gap between basic passes and higher achievement levels suggests that while access to the minimum standard has improved, the quality of learning remains uneven. In South Africa, the Post-School Education and Training (PSET) system, which includes the TVET colleges, is supposed to integrate Artificial Intelligence in the curriculum redesign, lecturer development, and digital infrastructure investment. Current planning documents and the National Digital and Future Skills Strategy explicitly position digital competence as a cross-cutting outcome and call for integrating ICT into programmes and pedagogy (Jagannathan, 2021). Within this policy document in the National Certificate Vocational (NCV) Mathematics, there is a need for technology integration because it connects many drawings, measurements, and algebra (Nedambale, 2024). However, technology on its own cannot guarantee transformation in teaching and learning; the successful integration depends on how mathematics didactics is used with it.

Research Problem & Rationale

Research Questions

As stated earlier, this study aims to examine how technology integration in the teaching of circle geometry at South African TVET colleges can inform curriculum design and policy development in mathematics education. The study seeks to bridge the gap between policy intent and pedagogical practice by exploring how technology-enabled teaching can enhance learners' understanding, lecturers' practice, and systemic curriculum frameworks, in alignment with the demands of the Fourth Industrial Revolution (4IR) and national education priorities. This study seeks to answer the questions:

1. What challenges and opportunities arise in integrating technology into geometry teaching within TVET contexts?
2. How do lecturers use digital technologies in teaching circle geometry, and what pedagogical strategies do they adopt?
3. How does technology integration inform curriculum design and teaching strategies in the instruction of circle geometry at the South African TVET colleges?

Review of Related Literature

Geometry is an important part of mathematics for the following reasons:

Firstly, it contributes to spatial reasoning and visualisation skills, which are not only foundational for more advanced mathematics (e.g., trigonometry, analytic geometry) but also increasingly relevant in STEM fields and in technologies that rely on spatial understanding (robotics and modelling).

Geometry remains central in mathematics education for several interconnected reasons. First, it contributes to spatial reasoning and visualisation skills, which are not only foundational for more advanced mathematics (e.g. trigonometry, analytic geometry) but also increasingly relevant in STEM fields and in technologies that rely on spatial understanding (CAD, robotics, modelling). For instance, Gamage and Charles-Ogan (2019) show that using technology (GeoGebra) in teaching circle geometry improves conceptual understanding in learners; therefore, both the learners’ performance and their interest improve.

Secondly, geometry develops logical and deductive reasoning, particularly through proof and theorems. Mudhefi et al. (2024) emphasise that beyond rote that include memorisation, learners also struggle with understanding properties of shapes, visualisation, and geometry terminology, which are critical for building deductive reasoning.

Thirdly, geometry, especially circle geometry, holds a place in curriculum policy and assessment in many countries (including South Africa), meaning that competence in this area is essential for learners’ success in national examinations and further studies. For example, Motseki and Jojo (2022) in their work in South African TVET colleges have discovered that using the Geometer’s Sketchpad significantly improved the understanding of circle geometry among Level 4 students. This is an indication that curricula that include geometry components that can align with technology use can lead to improved outcomes.

Finally, geometry also has key pedagogical benefits because it can serve as a basis for integrating other areas of mathematics (algebra, coordinate geometry), strengthen general mathematical thinking, and help with the transition from concrete to abstract reasoning. For instance, the use of Van Hiele's levels in several recent studies indicates that curriculum design that attends to how learners move through geometric thinking stages can make geometry teaching more effective (Bediako, 2021; Candiotes, 2023).

Within mathematics education, circle geometry remains a challenge for many learners because it is taught in abstract ways that fail to use digital tools for visualisation and exploration (Jones, 2003). Research demonstrates that the effective integration of digital technologies such as dynamic geometry software can enhance learners' conceptual understanding and reasoning (Guven, 2012; Leung et al., 2024). However, such practices are not systematically embedded within the Curriculum and Assessment Policy Statement (CAPS) under DBE or the curriculum frameworks of the TVET sector overseen by DHET (Vuthela & Ngumbela, 2024). The problem lies in the disconnect between the policy plan and curriculum implementation**.** While DHET and DBE call for ICT integration, they provide limited guidance on the pedagogical models and assessment practices needed to integrate technology meaningfully into mathematics education curriculum. Also, curriculum policy sometimes mandates geometry components without giving sufficient support (in teacher development workshops, resources, or assessment design) to ensure that geometry is taught in a way that fosters understanding rather than shallow coverage.

Teaching With Technology Using the TPACK Framework

This study was embedded within the theoretical framework of Technological Pedagogical Content Knowledge (TPACK)since it offers a means of exploring the key concepts in the study.

The Technological Pedagogical Content Knowledge (TPACK) framework was developed by Mishra and Koehler (2006). It extends Shulman's concept of Pedagogical Content Knowledge (PCK) by adding the technological dimension. TPACK suggests that effective teaching with technology requires the integration of three forms of knowledge: content knowledge (CK), which is the subject matter to be taught (in this case, circle geometry); pedagogical knowledge (PK), which refers to the teaching strategies; and technological knowledge (TK), which relates to the use of digital tools and resources. The value of TPACK lies in highlighting that these domains cannot operate in isolation; therefore, teachers need integrated knowledge that combines technology, pedagogy, and content to design meaningful, technology-enhanced learning experiences (Koehler et al., 2013).

The TPACK framework is relevant to this study because it explains how and why lecturers integrate technology into the teaching of circle geometry. Mathematics teaching often requires learners to move between abstract reasoning and visual representations, making the thoughtful use of digital tools such as GeoGebra particularly powerful. However, research has shown that access to technology alone is insufficient; teachers must develop the pedagogical and content expertise needed to use these tools effectively (Alenezi, 2017; Bingimlas, 2009). Within the South African TVET sector, where lecturers often face uneven professional development opportunities and infrastructural challenges, the TPACK framework provides a useful lens for analysing both successes and shortcomings in technology use. By applying TPACK, this study can inform whether lecturers are replacing traditional methods with digital equivalents or whether they are getting deeper integration where technology reshapes the way circle geometry is taught and understood. Such insights are important not only for improving classroom practice but also for informing curriculum design and policy development under the directives of DHET and DBE.

Methodology

Interpretive Research Paradigm

This study was framed within an interpretive research paradigm, which seeks to understand how individuals construct meaning within their specific contexts (Pervin & Mokhtar, 2022). Five mathematics lecturers who are teaching in South African TVET colleges were the participants. They were purposively sampled from a group of fifteen participants who teach mathematics at five different colleges. These participants were purposively selected because of their direct involvement in teaching circle geometry and their varying levels of experience with technology (Campbell et al., 2020).

The questionnaire that was used for this study belongs to a qualitative study. This study employed the Open-ended Questionnaires and the semi-structured interviews: These were used to gather baseline information on lecturers' experiences, perceptions, and practices related to technology integration. Together, these methods ensured data triangulation, enhancing the credibility and trustworthiness of the findings.

The interview analysis began with coding the themes that were identified from the data collected. The themes were created around the technology use of lecturers in the teaching of circle geometry, with the expectations for changing the education policies at the TVET Colleges.

Ethics strategies were observed before, during, and after this qualitative study. Before conducting the study, a gatekeeper application was written to the Department of Higher Education and Training and the college rector to conduct this qualitative study in three different campuses of the TVET College located in the Majuba district. Permission to conduct the study was granted. Also, consent letters were written to mathematics lecturers who teach level 4 (participants), requesting them to be engaged in the study.

Each participant had a consent letter addressed to them, where they were made aware that they had a right to consent to the letter by signing or to refuse to be part of the study. All participants who consented were called to the lecture theatre to inform them of the study, the phenomenon, purpose, and objectives. They were also informed that they had a right to withdraw during the study.

The participants' anonymity and confidentiality rights were taken into consideration. All participants were provided with my contact details and individual appointments to meet the privacy criteria. I also asked permission to conduct a study from the Research Office of the University of KwaZulu-Natal, where ethical clearance was approved.

During the study, all ethical issues were observed by avoiding mistreatment of the participants regarding age, religion, family background, culture, gender, and race. During data collection, confidentiality and anonymity of the participants were maintained using (lecturer A, lecturer B, lecturer C, lecturer D, and lecturer E) respectively, not using their real identification. It was disclosed to the lecturers that the study had no remuneration and was voluntary. The clear, appropriate, and straightforward language was used. Sharing data with other researchers and other participants was avoided. Participants were informed that copies of the data would be sent to them. Confidentiality for this study was taken into consideration. Participants were informed that data would be kept for five years in a safe cabinet at the university.

Findings and Discussions

Disparities in Technology Access

This theme was identified because the lecturers demonstrated varying levels of comfort and competence with digital tools, highlighting the need for differentiated professional development. The lecturers gave various meanings concerning the access.

All the lecturers gave different opinions concerning the various experiences with technology access. This revealed inequities in access to technology among both lecturers and students. Some colleges were better resourced, enabling lecturers to experiment with dynamic geometry software and online platforms, while others had little to no access. As mentioned above, lecturers reported that many TVET colleges lacked adequate computer laboratories, projectors, and access to licensed dynamic geometry software. Even where resources existed, they were often outdated or poorly maintained. This limitation not only hindered innovative teaching but also restricted students' exposure to technology-enhanced learning, reinforcing a reliance on traditional chalkboard methods.

This suggests that the students from disadvantaged backgrounds also lack personal devices or reliable internet connections, which creates disparities in participation and learning outcomes. These inequalities limited the scalability of technology integration and highlighted the need for policy interventions that prioritise equitable access.

Pedagogical Opportunities

Technology was seen as valuable in visualising abstract concepts in circle geometry, particularly through dynamic geometry software, which enhanced learners' conceptual understanding. When the participants were asked: How has technology changed how your students learn geometry?

The lecturer's use of technology can transform the teaching and learning of circle geometry by enabling the learner-centred visualisation of abstract concepts. This suggests that using technology has shifted from content delivery to an inclusive pedagogy that prioritises perspectives.

The use of online resources and software illustrates the potential of digital tools to scaffold spatial reasoning, allowing learners to manipulate and view shapes from different angles, thereby addressing challenges such as difficulty in imagining 3D objects. This resonates with the TPACK framework, where technology is not merely an add-on but a core enabler of conceptual understanding. From a curriculum and policy perspective, this underscores the need to integrate visualisation tasks using technology into the mathematics curriculum, while ensuring equitable access to digital tools across TVET colleges. Moreover, this emphasises the potential of technology to remediate learners' foundational weaknesses in mathematics, while also highlighting gaps in curriculum design and lecturer preparation that must be addressed at both institutional and policy levels.

Contextual Challenges

One of the participants mentioned that there is a challenge to use the technology due to some experienced challenges on campus.

Lecturers identified significant barriers, including limited access to ICT infrastructure, unreliable internet connectivity, and a lack of institutional support. The lecturer's statements address the contextual challenges that prevent the integration of technology in mathematics teaching and learning within TVET colleges. Although technological infrastructure, such as smartboards and data projectors, is physically available, it is often vandalised, misused, or left idle due to limited lecturer awareness and a lack of institutional support. The shared use of classrooms with colleagues who are not trained to operate available technologies further complicates the problem, also reflecting the systemic gaps in professional development. Moreover, the absence of reliable internet connectivity and restrictions on installing free educational software such as GeoGebra highlight structural and bureaucratic barriers that prevent lecturers from fully utilising digital resources. These issues point to a broader disconnect between policy aspirations and classroom realities: while curricula and policy frameworks encourage technology integration, resource degradation, theft, poor maintenance, and rigid ICT policies severely constrain practice. This testimony underscores how contextual barriers, ranging from infrastructure insecurity to institutional resistance, limit the transformative potential of technology for enhancing learners' understanding of mathematics.

Curriculum and Policy Implications

Participants expressed the need for curriculum guidelines that explicitly incorporate technology use in mathematics teaching, suggesting that policy frameworks often lag behind classroom realities.

Participants expressed the need for curriculum guidelines that incorporate technology use in mathematics teaching. They suggested that policy frameworks often have a gap behind classroom realities. While national and institutional policies encourage the integration of digital tools, they frequently lack concrete guidelines on how lecturers should embed technology into specific mathematical topics, such as circle geometry. As a result, technology use is often left to individual use, dependent on lecturers' initiative, digital literacy, and access to functional resources. This creates uneven implementation across colleges, with some lecturers attempting to integrate while others avoid technology altogether due to uncertainty or lack of training. The absence of curriculum-embedded strategies also means that lecturers are not supported in linking technology with learning outcomes, assessment practices, or remediation of learners' conceptual gaps. Consequently, even where technological infrastructure is available, its pedagogical potential is imbalanced in its use. Within this conference context, this gap underscores the challenge of aligning high-level policy intentions with practical curriculum design and classroom execution. It highlights an urgent need for curriculum guidelines that go beyond aspirational statements to provide clear, discipline-specific pathways for embedding technology into mathematics teaching, ensuring consistency and equity across the TVET sector.

Professional Identity and Confidence

Some lecturers felt that technology integration challenged their traditional teaching methods, while others embraced it as an opportunity for professional growth.

Some lecturers felt that technology integration compromised their traditional teaching methods, while others took it as an opportunity for professional growth. For those who enjoyed the traditional chalk-and-talk approaches, the shift towards digital tools disturbed their comfort zone and raised questions about their competence and authority in the classroom. Feelings of uncertainty, frustration, and even resistance emerged when lecturers were expected to explore unfamiliar software or manage technical difficulties in front of learners. This often undermined their confidence, stressing that technology was imposed rather than a norm of their professional practice. In contrast, other lecturers viewed technology as a means to redefine and enrich their professional identity, positioning themselves as innovators who could make mathematics more accessible and engaging. For these participants, experimenting with tools such as dynamic geometry software not only boosted their confidence but also cultivated a sense of pride in adapting to modern pedagogical demands. The divergence in responses highlights a key challenge: professional identity in the TVET sector is unevenly shaped by lecturers' prior experiences, access to training, and institutional support. Within this conference paper framework, this underscores the importance of structured professional development that both validates traditional expertise and equips lecturers with the confidence to integrate technology meaningfully, enabling a shift from resistance to professional empowerment.

Limitation of the Study

The limitation of this study involved the lecturers who taught level 4 mathematics because of the study scope of geometry, which is only done at the exit level. This influenced the generalisation of study in other areas. A qualitative study was used to apply a case study with one-on-one interviews and an open-ended questionnaire. Observations were not done since they may take too long to complete, considering the pandemic era where Covid-19 limits the number of people in the classrooms.

Future Recommendations

Based on the implications, the following recommendations can be made to improve the teaching and learning of circle geometry in TVET colleges:

1. Enhance Technological Infrastructure in TVET Colleges

Recommendation: Colleges should prioritise upgrading and maintaining ICT facilities, including computers, projectors, and licensed dynamic geometry software. Adequate access to technological resources will enable lecturers to integrate digital tools more effectively, moving beyond traditional chalk-and-talk methods.

Rationale: Without reliable and functional infrastructure, the potential of technology to transform mathematics teaching remains unrealised. The recurring issues of vandalism, outdated equipment, and lack of software access, as expressed by participants, highlight that lecturers are often forced to revert to traditional chalk-and-talk methods. Upgrading and maintaining ICT facilities is therefore a foundational requirement: it provides the basic conditions under which innovative teaching practices can flourish and ensures that policy aspirations are not undermined by material constraints.

2. Professional Development in Integrated TPACK

Recommendation: Structured training programs should be developed to help lecturers build not only CK, PK, and TK but also TCK, TPK, and full TPACK. Workshops and continuous professional development (CPD) initiatives should focus on practical strategies for combining technology, pedagogy, and content knowledge, specifically in the context of circle geometry.

Rationale: Even where infrastructure exists, lecturers struggle to integrate technology effectively if they lack the pedagogical confidence and integrated knowledge base to do so. Participants frequently reflected on their tentative, exploratory use of tools such as dynamic geometry software, revealing gaps in their TCK, TPK, and TPACK. Structured CPD opportunities will not only build lecturer confidence but also support the redefinition of professional identity in a technology-rich environment, moving beyond surface-level use of tools to meaningful integration that improves learner outcomes.

3. Strengthen Students' Foundational Mathematics Skills

Recommendation: Colleges should implement remedial or bridging programs for students with weak mathematical backgrounds before introducing technology-intensive learning. Early intervention will ensure students are better prepared to engage meaningfully with technology-enhanced instruction.

Rationale: The success of technology integration is not only dependent on lecturer readiness but also on learner preparedness. Many students in TVET colleges enter with significant gaps in foundational mathematics, which hinders their ability to engage productively with technology-enhanced instruction. For example, dynamic software may allow visualisation of geometric concepts, but without basic algebraic or spatial reasoning skills, learners cannot fully benefit from such affordances. Remedial and bridging programs are therefore necessary to level the playing field, ensuring that technology serves as an enhancer rather than a barrier to learning.

4. Address Disparities in Technology Access

Recommendation: Policies should aim to reduce inequities in access to devices, software, and internet connectivity. Partnerships with the private sector, government funding, or blended learning approaches could ensure that all students and lecturers can participate equally in technology-supported mathematics teaching.

5. Curriculum and Policy Alignment

Recommendation: The findings under this theme suggest that the curriculum frameworks should integrate technology strategies in mathematics courses. This should give clear guidelines and directives on how lecturers should use digital tools within the content teaching, assessment, and student engagement practices.

Conclusion

This study has highlighted the complex interplay between technology integration, lecturer readiness, student preparedness, and institutional constraints in the teaching of circle geometry within South African TVET colleges. While technology holds significant promise for enhancing learners' spatial reasoning and bridging gaps in conceptual understanding, its impact is severely constrained by contextual challenges such as inadequate infrastructure, vandalism, inequitable access, and rigid ICT policies. Lecturers' reflections further reveal that their professional identity and confidence are shaped by the extent to which they are supported through structured professional development and curriculum guidelines that move beyond aspirational policy statements to concrete classroom practices. At the same time, students' weak mathematical foundations remain a critical barrier, underscoring the need for targeted interventions that prepare them to engage meaningfully with technology-enhanced learning.

For DHET and other stakeholders, the insights offered here provide direction for designing responsive curriculum frameworks and institutional policies that acknowledge the realities of the TVET context while leveraging the transformative potential of digital tools. Ultimately, sustainable integration of technology in mathematics teaching will depend not only on resources but on the collective effort to reimagine pedagogy, strengthen professional practice, and create enabling conditions that position TVET colleges as drivers of educational innovation and equity. The resolution of such problems could enhance learning performance as well as practice teaching alignment with the Department of Higher Education and Training (DHET) strategic intentions for skill development (Paterson et al., 2024).

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

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