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Contextualising ICT integration in rural science classrooms: A case study on the influence of digital tools on physical sciences teaching and learning in South African schools

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Abstract

This study aims to explore the contextualisation of Information and Communication Technology (ICT) in the teaching and learning of physical sciences in rural high schools in the O.R. Tambo Region of South Africa. Grounded within the Technological Pedagogical Content Knowledge (TPACK) framework, it provides a structured lens for understanding how teachers navigate the intersection of technology, pedagogy, and subject knowledge in resource-constrained environments. A qualitative case study approach was adopted for this study. Interviews and classroom observations were conducted with ten teachers and ten learners from five rural high schools. The collected data were analysed using thematic analysis. Findings indicate that learners and teachers are the primary users of ICT tools in classrooms, with teachers and learners reporting limited use of ICT in teaching and learning of physical sciences. Moreover, the teachers demonstrated limited proficiency in utilising new application tools and platforms. However, challenges such as limited infrastructure, inadequate training, and inconsistent internet connectivity hinder effective ICT integration. This study highlights the necessity for enhanced ICT training programmes for teachers and learners, improved infrastructure, and policy support to maximise the benefits of ICT in physical sciences education. The findings provide valuable insights for teachers, policymakers, and stakeholders aiming to enhance digital science teaching and learning in South African rural high schools.

Keywords: Information and communication technology, Learning, Physical sciences, Teaching, Teachers, Learners.

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Contents

Contribution of this paper to the literature
This study contributes to the existing literature by providing a detailed, context-specific utilization of ICT in rural South African schools, an area that is still inadequately represented in global research on digital education and further expands the use of the TPACK framework in rural science education.

1. Introduction

The integration of Information and Communication Technology (ICT) in education has emerged as a transformative force globally, with the potential to redefine teaching and learning processes across subject areas. Previous research has demonstrated that the integration of ICT into the educational process has improved the learning experience and optimized students' active learning capabilities (Amutha, 2020; Habimana et al., 2025; Musokhonovna, 2021; Zidny, Sjöström, & Eilks, 2020). This is due to the significant pedagogical contributions that technology in education makes, as the implementation of ICT can facilitate effective learning through the assistance and support of ICT elements and components (Habimana et al., 2025). It is accurate to assert that technology-based tools and equipment can facilitate the acquisition of knowledge in nearly all major disciplines, including mathematics, science, languages, arts, and humanities (Rahmi, Syahmani, Mahardika, Suyidno, & Suwandy, 2025). In particular, in science education, technology-based teaching and learning can provide a variety of engaging methods to enhance the learning experience and make it more meaningful (Almasri, 2024; Ghavifekr & Rosdy, 2015). The significance of technical support in enabling teachers to utilize ICT in the classroom has been acknowledged by schools in countries such as India, the Netherlands, Turkey, the United Kingdom, and Malta (Özkan & Tekeli, 2021; Yang & Wang, 2012).

In African countries such as Ghana, Nigeria, and Tanzania, significant strides have been made in introducing and implementing national ICT policies and digital literacy programs to bridge the digital divide (Agabi, Agbor, & Ololube, 2015; Ngodu, Ndibalema, & William, 2024; Ofosu-Asare, 2024). Yet, the realities on the ground, marked by unreliable electricity, poor internet connectivity, and limited pedagogical support, have restricted ICT's impact on education and, in particular, on science education (Adomi & Kpangban, 2020). These challenges are echoed in the South African context, where rural schools often struggle with similar constraints despite national investments in ICT infrastructure and policy reform (De & Kaugi, 2023; Mathevula & Uwizeyimana, 2014).

In South Africa, the policy regarding ICT integration was initially established in the Millennium Development Goals (MDG) Target 8.F, which articulates that *"in cooperation with the private sector, make available the benefits of new technologies, especially information and communications."* Consequently, the educational experience and cognitive development of learners could be significantly impacted by the prudent adoption and utilization of ICTs in schools. The White Paper on e-Education (Department of Education (DoE), 2004) in South Africa posits that the incorporation of ICTs into education is an essential element of the government's strategy to improve the quality of learning and teaching in educational and training settings. Department of Education (DoE) (2004) elucidates the capacity of ICT to improve the pedagogical experiences of teachers and students. This is based on the assumption that (a) the integration of ICT into pedagogy is a vital lifelong skill for both teachers and learners, and (b) encouraging teachers to utilise ICT in their instruction will enhance educational quality. Nevertheless, as per Tezci (2011) quoting *"Teachers should learn not only to use technology to enhance traditional teaching or increase productivity, but also to learn from a student-centred perspective how ICT can be integrated into classroom activities in order to promote student learning" (p. 116).*

In particular, in science education, the government has implemented initiatives to improve the teaching and learning of physical sciences in South African Schools. The Department of Basic Education (2018) developed a strategy to provide schools with ICT training to facilitate the provision of electronic/digital content, the establishment of digital libraries and multimedia resources, the broadcast of electronic content through SABC and community radio stations, the provision of tools such as tablets and laptops with trackers, the full utilization of teacher centres for professional development, the online training of officials and teachers, and the provision of technical support, all contributing to enhance ICT education in schools.

However, despite the commendable efforts by the government to integrate ICT into teaching and learning, inadequate performance in science subjects persists. Malekani (2018) and Ndume, Kisanga, and Selemani (2021) propose that teachers may encounter insufficient knowledge regarding ICT strategies for teaching science subjects, or they may face structural and infrastructural challenges, indicating the inappropriate use of ICT in the teaching of science subjects, and the adequacy of teachers' knowledge to effectively utilise this technology in their pedagogy. According to Shambare and Jita (2024) this issue is especially pertinent with teachers in rural schools who may lack training in technology integration within their first teacher education curricula. Therefore, Banini (2019) assert that meaningful technology integration occurs when a deliberate pedagogical goal directs the selection of specific technologies to enhance particular teaching methods. This educational objective must be clearly established in curriculum-related and instructional activities. Koehler and Mishra (2009) asserted that successful technology integration into pedagogy is attainable only when teachers possess specialised knowledge for teaching with technology, referred to as technological pedagogical content knowledge (TPACK). TPACK embodies a teacher's knowledge of content, pedagogy, and technology, allowing for the development of suitable and context-specific instructional strategies. TPACK serves as the cornerstone for proficient instruction utilising educational technologies, necessitating comprehension of epistemological theories and the ways in which technologies can enhance knowledge, introduce novel epistemologies, or reinforce established ones. Koehler and Mishra (2009) argue that although the TPACK framework has been widely adopted in research and practice, it remains under-theorised, especially regarding how technology as a domain relates to teacher knowledge and practice. To address this gap, the authors synthesise three theoretical perspectives: philosophy of technology, situated cognition, and design science to deepen understanding of what TPACK means and how it can be developed. Their analysis highlights that technology should not be treated merely as an add-on to pedagogy and content but understood conceptually in relation to teaching goals and contexts. They further suggest that TPACK is best seen not just as a static set of knowledge components but as a situated, constructivist form of teacher knowledge that emerges through active design and reflective practice. This framing emphasises the active role of teachers as designers of technology-enhanced learning and provides a theoretical foundation for fostering TPACK development in teacher education. Consequently, for rural school science teachers, obtaining TPACK would indicate their capacity to enhance their science instruction by leveraging the intrinsic advantages of integrating successful virtual learning.

By centring teachers' pedagogical knowledge and students' engagement with digital tools, the study aims to generate insights that go beyond superficial measures of ICT adoption and delve into the deeper pedagogical transformations required for equitable and meaningful technology integration. In doing so, this study contributes to the body of research on ICT in science education and provides evidence-based recommendations for policy, teacher development, and curriculum reform. It situates rural science classrooms not as passive recipients of technology but as complex, adaptive systems where innovation, context, and professional capacity intersect to shape educational outcomes.

1.1. Research Questions

The study sought answers to the following questions:

1. What is the availability and utilisation of ICT facilities among physical sciences teachers and learners in high schools?
2. What factors influence the use of ICT for teaching and learning physical sciences in schools?
3. What strategies can physical sciences teachers implement to enhance ICT integration in teaching and learning?

2. Literature Review

Following the transition to democracy in 1994, South Africa's Department of Education introduced the first White Paper on Education and Training (Department of Education (DoE), 1995), laying out a comprehensive vision for transforming education. This foundational document emphasised the importance of exploring technological integration within the education system. A decade later, the e-Education White Paper (Department of Education (DoE), 2004) emerged as the country's primary and, to date, only policy framework guiding the integration of ICTs into teaching and learning. The policy underlines the government's commitment to equipping students with 21st-century skills by leveraging ICTs to improve educational quality. It also calls for cooperation between the government and the private sector to develop schools into centres of quality teaching and learning through strategic ICT implementation (Department of Education (DoE), 2004). The policy envisions a phased approach, with the final phase aiming for full integration of ICTs across all educational levels. However, despite the ambitious goals, the policy acknowledges the substantial financial investment required, and the lack of a dedicated national budget for implementation remains a major constraint.

A report by the Human Sciences Research Council (HSRC) (Tlabela, Roodt, Paterson, & Weir-Smith, 2007) provided a baseline for understanding the disparities in ICT access. Within South African schools, there is wide variation in the availability and quality of ICT resources. Many schools face challenges such as an inadequate number of computers, limited teacher proficiency in ICT, lack of technical resources, insufficient ICT availability, inadequate training on pedagogical integration, and a lack of curriculum support (Makgato, 2014; Qazi et al., 2022). This is consistent with international studies, which indicated that many schools face similar challenges such as an inadequate number of computers, limited teacher proficiency in ICT, and a lack of technical resources (Papadimitropoulos, Dalacosta, & Pavlatou, 2021; Park, Kim, & Park, 2021; Xiong, Ching Sing, Tsai, & Liang, 2022). Other studies have indicated that teachers' attitudes towards ICT have a substantial impact on their propensity to incorporate digital tools into their classrooms (Qaddumi, Bartram, & Qashmar, 2021; Suleiman, Yahya, & Tukur, 2020). Azlan et al. (2020) and Venketsamy and Hu (2022) indicated that a significant number of teachers employ ICT for routine tasks such as internet searches, rather than for active learning. Molenda (2023) has observed that ICT frequently prioritises administrative functions over active learning. Hence, Venketsamy and Hu (2022) contended that teachers' ICT proficiency could be enhanced through the development of positive motivation, computer literacy, and methodological skills.

In the context of Physical Sciences, ICT plays a crucial role in facilitating conceptual understanding, improving engagement, and supporting innovative pedagogies. One of its primary advantages is its ability to enhance the quality of instructional delivery through interactive and multimedia-based resources. Technologies such as simulations, animations, and virtual laboratories help make abstract and complex scientific concepts more tangible and accessible, as teachers incorporate ICT into instruction (Du Plessis & Letshwene, 2020; Isyanov, Rustamov, Rustamova, & Sharifhodjaeva, 2020). Through these digital resources, students can visualize molecular interactions, chemical reactions, and physical phenomena that would otherwise be challenging to demonstrate in a traditional classroom setting. Moreover, ICT provides students with access to vast educational resources through online learning platforms, thereby supporting independent and inquiry-based learning (Papadimitropoulos et al., 2021). Additionally, Valverde-Berrocoso, Fernández-Sánchez, Revuelta Dominguez, and Sosa-Díaz (2021) emphasised that ICT enhances traditional instruction by facilitating flexible learning through online platforms.

Nonetheless, Suleiman et al. (2020) emphasised that the successful integration of ICT necessitates both technological and pedagogical expertise to foster self-directed learning, allowing students to explore topics beyond the standard curriculum at their own pace. However, the successful integration of ICT in education is contingent upon the socio-cultural context, teacher competence, administrative support, and infrastructure availability (Anthonysamy, Koo, & Hew, 2020; Valverde-Berrocoso et al., 2021). The literature underscores the importance of professional development, curriculum development, stakeholder collaboration, and community engagement as critical strategies for promoting the effective utilisation of ICT (Boateng & Marwanqana, 2024).

At a theoretical level, proposed the Technological Pedagogical Content Knowledge (TPACK) framework, initially termed TPCK, to assist teachers in integrating technology into their instructional methodologies. Figure 1 illustrates the TPACK framework employed in this study. Figure 1 shows the interplay among three essential categories of teacher knowledge: content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK). The TPACK framework comprises three critical domains: CK, PK, and TK. CK pertains to the teacher's comprehension of the subject matter, PK to their mastery of effective teaching and learning strategies, and TK to their knowledge of technologies, including their effective use in educational settings. The model also emphasises the intersection of three knowledge areas: Pedagogical Content Knowledge (PCK), which is concerned with strategies for ensuring that subject matter is comprehensible to students Technological Pedagogical Knowledge (TPK), which investigates the ways in which specific technologies alter teaching methods; and Technological Content Knowledge (TCK), which examines the ways in which technology affects the delivery and comprehension of content (Shulman, 1986).

In this context, effective teaching relies on adaptable access to comprehensive, well-structured, and interconnected knowledge across various domains, encompassing understanding of student cognition and learning; mastery of the subject matter; and, progressively, proficiency in technology. Mishra (2019) introduces the concept of Contextual Knowledge (XK), which pertains to teachers' understanding of the situations under which their classroom instructions take place, emphasising the significance of the educational environment. The XK encompasses information derived from the ICT provided at the school, while also integrating knowledge about the educational environment.

From a teacher education perspective, this expansion provides an opportunity for intentional intervention but also enhances their understanding of the unique challenges and affordances of their specific teaching contexts. Without this contextual insight, efforts to apply TPACK principles in classrooms may fall short in areas where limited access to digital tools, electricity, or internet connectivity poses daily obstacles. Therefore, the lack of contextual knowledge can significantly hinder a teacher's ability to meaningfully apply ICT in teaching. Hence, this framework is highly relevant to the current study to allow for a nuanced analysis of how teachers integrate ICT tools within their content areas and teaching methods in rural schools within the OR Tambo Inland District. By examining the intersections of technology, pedagogy, content, and contextual knowledge, this framework supports the investigation into both the effectiveness of ICT use and the challenges teachers face in doing so. It also provides a structure for interpreting students' experiences and responses to ICT-supported lessons.

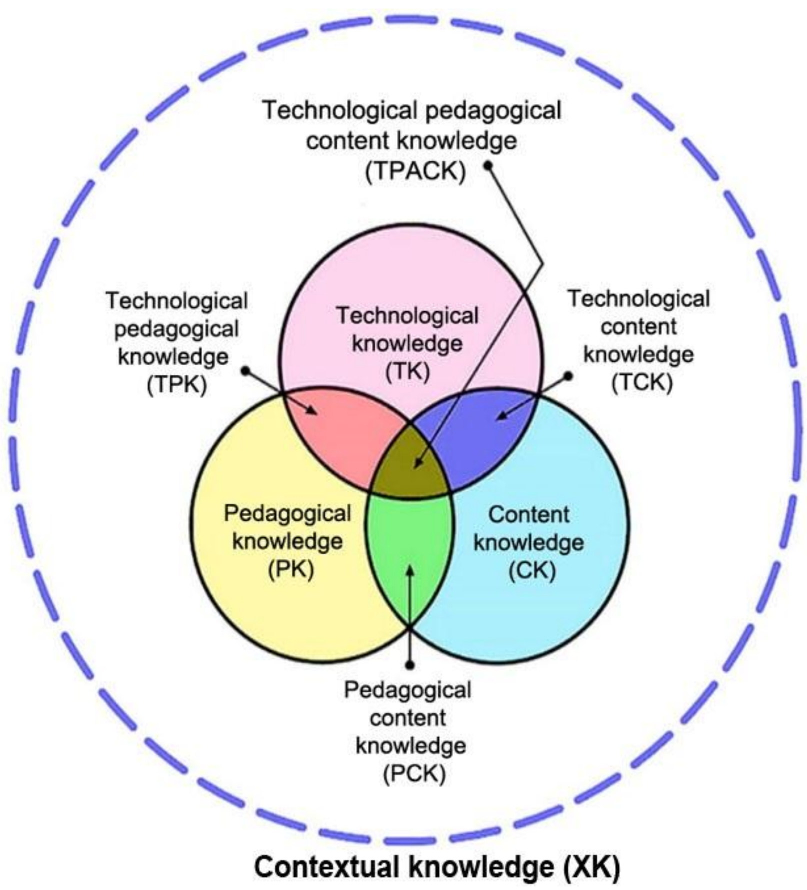

Figure 1 illustrates the TPACK model.

Source: Mishra (2019).

3. Methods

In this study, the researchers employed an interpretivist paradigm and aligned themselves with the assertion by Hammersley (2013). This paradigm is well-suited for studying diverse perspectives, which can not only describe objects, individuals, or events but also provide profound insights about them within their social context. This paradigm helped the researchers to perform an exploratory study to determine how physical science teachers experience the use of ICT in their schools in rural settings, by detailing their lived experiences of ICT integration in physical sciences teaching and learning.

This study employed qualitative research. Denzin and Lincoln (2011) assert that qualitative research concentrates on genuine, lived experiences and contexts as they occur in everyday life, aiming to comprehend experiences rooted in real situations. This approach seeks to understand how teachers and learners interpret things in their natural environments as teachers integrate ICT tools in their science classroom context, as asserted by

Lune and Berg (2017). The case study design was employed in this study. The case study design emphasises the exploration of one or several cases over a period, employing a comprehensive insight into various information sources (Yin, 2018). This approach is optimal for scenarios that involve investigating under-explored and authentic phenomena, particularly when the contexts are intricate, and researchers have limited control over the phenomena (Creswell & Poth, 2016). From Miles, Michael, and Johnny (2014), a case is "a phenomenon of some sort occurring in a bounded context" (p. 25). In this study, a multiple case study design was deemed suitable for the researchers to seek to comprehend the implementation of ICT in the teaching and learning of physical sciences in schools in the rural district of the O.R. Tambo Inland schools to understand the influence of the rural diverse contexts on ICT usage. The study targeted all high schools within the O.R. Tambo Inland District. Within the district, the study purposefully sampled five high schools. These schools are all rural and have experienced a similar socio-economic background with limited resources. The target population comprised physical sciences teachers and learners from rural secondary schools in the O.R. Tambo Inland District. These participants were selected based on their direct engagement with ICT in science education. In each school, the study purposefully sampled two physical sciences teachers, totalling ten teachers. In each of these schools, the researchers randomly selected two physical science learners, totalling ten learners.

The researchers utilise interviews and classroom observations as the main data collection instruments. The interview questions were semi-structured and comprised ten items that capture teachers' and learners' experiences with ICT availability and usage, their challenges, and their beliefs in the teaching and learning context. The classroom observation schedules were also developed in line with the study objectives.

After obtaining permission from the school authorities and establishing rapport, including with the teachers and the learners, the researchers arranged a time to observe the teachers in their classrooms. The observation was non-participatory, as the researchers did not ask questions or speak during the lessons. One observation was made per teacher. One week after the classroom observation was conducted, interviews with the teachers and the learners were conducted. Each interview lasted for 30 minutes, and they were audio recorded with the permission of the interviewees. Although the interviews were semi-structured, the researchers employed a narrative and conversational approach, often participating in respondents' regular activities to accomplish this objective.

The study employed Braun and Clarke (2006) six steps of analysing data with the thematic analysis technique: (a) acquainting oneself with the data, (b) developing preliminary codes, (c) identifying themes, (d) evaluating themes, (e) identifying and naming themes, (f) report generation with the completion of thoroughly developed themes, which entails the final analysis and composition of the report. The codes, or classifications assigned to each thought, were subsequently contextualized with one another to produce themes. A theme encapsulates a significant aspect of the data concerning the research topic and signifies a degree of structured response or meaning within the data set. Themes were further categorized into sub-themes.

To ensure trustworthiness, the researchers established trust by prolonged engagement with the participants in each school through continuous observation in the field, interaction with participants, and meticulous observation of their activities, allowing the researchers to gain thorough insights (Dodgson, 2019). Furthermore, the application of triangulation, which entails the amalgamation of interview data, observation, and field notes, aids in corroborating findings, hence augmenting their credibility (Gunawan, 2015). The captured transcripts were returned to the participants for member checking to enhance the degree of confirmability.

The researchers obtained ethical approval from Walter Sisulu University's Faculty of Education (Protocol number: FEDFREC 2444) and the Eastern Cape Department of Education to conduct the study in selected schools. Permission from school principals was secured, and the study's purpose, methodology, and duration were explained to them. Physical sciences teachers and learners (with their parents) voluntarily consented to take part in the study. Special care was taken to protect learners as a vulnerable group, using coding and pseudonyms to ensure anonymity and confidentiality, in line with Heaton (2021) suggestion.

4. Findings

4.1. Profile of Physical Sciences Teachers

A total of ten teachers participated in the study, with representation from schools A to E. The data shows that there were more male teachers (n=6) than female teachers (n=4). All the teachers were qualified to teach Physical Sciences in the FET phase, holding either a Bachelor of Science degree accompanied by a Postgraduate Certificate in Education (PGCE) or a Bachelor of Education degree in Natural Sciences. These qualifications align with national standards for teaching Physical Sciences in Grades 10 to 12. The age of the teachers ranged from 28 to 42 years, with all of them being older than 25. Each of the teachers had more than six years of teaching experience in Physical Sciences. The subjects taught include Physical Sciences, and in some cases, combinations with Mathematics or Chemistry. All the teachers are South African citizens. To maintain confidentiality and adhere to ethical research standards, each teacher was assigned a pseudonym: PHYSCT A1, PHYSCT A2, and so forth.

4.2. Learner Background Profile

A total of ten learners participated in the study. There were more female learners (n=6) than male learners (n=4), indicating a gender distribution skewed in favor of female participation in Physical Sciences. The majority of the learners were 18 years old (n=6), followed by 2 learners aged 19 and 2 learners aged 17. This age range is consistent with the typical age for learners in Grades 10 to 12 in the South African education system. The grade distribution was relatively even, with 3 learners in Grade 10, 3 in Grade 11, and 4 in Grade 12. The demographic data presented provides context for understanding the broader learning environment and supports the interpretation of findings related to the teaching and learning of Physical Sciences in the region.

4.3. Generated Themes

The themes presented below are organized in alignment with the research questions and objectives of the study. They reflect both individual and shared experiences among teachers and learners, highlighting the realities, challenges, and opportunities related to ICT integration in under-resourced rural settings. Classroom observations were used to validate and triangulate the interview data, ensuring credibility and a deeper understanding of the contextual dynamics in each school.

The four major themes that emerged from the data are as follows: the availability of ICT facilities, the utilisation of ICT by Physical Sciences teachers and learners, factors influencing the use of ICT, and strategies and plans for better integrating ICT, which captured the practical solutions proposed by teachers to improve digital integration.

4.3.1. Theme 1: Availability of ICT for Teaching and Learning

The data collected from both learners and teachers revealed a mixed landscape regarding access to ICT facilities in schools. While certain core technologies such as desktop computers, internet connectivity, and printers appeared to be fairly available across schools, significant disparities were evident in access to mobile and more flexible learning tools such as tablets, laptops, and USB drives. Learners reported that desktop computers and printers were generally available but inadequate. These tools formed the backbone of ICT-supported learning in most schools. However, other ICT resources were either scarce or inconsistently distributed.

The results showed that ICT facilities were not always available in the same way, and this was typically due to the location of the school, budget, and management support. One teacher responded: *We do have some computers, but they are either broken or locked up in the principal's office since there is not enough security. There are also a number of times when the power goes out here. So, I cannot utilise them* (PHYSCTD2). This shows that there are structural impediments to access, which is a common problem in rural areas with few resources, as alluded to by De and Kaugi (2023). The lack of ICT infrastructure makes it harder for both teachers and learners to take advantage of technology-enhanced instruction. While internet-enabled cell phones were relatively common among learners, their utility was sometimes constrained by school policies that prohibited cell phones. Nonetheless, many students used their personal devices to connect to school Wi-Fi for academic purposes, although network reliability varied. As one student described, *the Wi-Fi* was *accessible to all students during school hours, although sometimes the network is poor* (PHYSCLA1). *Another added that "we use our cell phones to receive learning materials via WhatsApp" (PHYSCLD2),* highlighting the growing role of mobile learning and instant messaging platforms. Another learner echoed this sentiment: *"Yes, there is a CAT Lab with desktop computers available for students. There are also portable laptops and notepads, but these are for teachers only" (PHYSCL A1).* This participant highlighted the presence of a Computer Applications Technology (CAT) laboratory equipped with desktop computers intended for learner use. While this indicates that the school has invested in ICT infrastructure, access appears to be restricted or unequal. *"Our school has Wi-Fi accessible to all students during school hours, although sometimes the network is poor"* (PHYSCL B1). This response reveals that, while internet access via Wi-Fi is technically available to students, its reliability is questionable. Unstable network connectivity hampers the effective use of online resources, making it difficult for students to consistently access educational platforms, conduct research, or submit assignments online. The intermittent nature of the network could lead to frustration among students and discourage them from relying on digital tools as part of their academic routines. This underscores how the mere availability of infrastructure without reliable service quality may fail to translate into meaningful ICT integration. Another student asserted, *"We have a computer lab with a whiteboard only, but no computers; it is used as a classroom" (PHYSCL E1).* This statement draws attention to the underutilization or repurposing of ICT facilities due to the absence of necessary hardware. A space designated as a computer lab functions merely as a regular classroom devoid of computers. This reflects a mismatch between infrastructure planning and resource allocation. It also suggests missed opportunities for students to develop computer skills in a dedicated environment, which could have a detrimental effect on their technological competencies and preparedness for tertiary education or the job market.

4.3.2. Theme 2: Utilisation of ICT for Teaching and Learning

The findings from the study highlight mixed experiences and perceptions among both students and teachers regarding the utilization and effectiveness of ICT tools in the teaching and learning of physical sciences. Many learners reported varying levels of access and satisfaction with ICT facilities. While nearly half (n=4) believed the quality of facilities was good, others, particularly in Schools C, D, and E, expressed dissatisfaction due to issues such as poor internet connectivity, lack of smartboards, and absence of basic ICT tools. This reflects a digital divide that limits equal learning opportunities. In terms of adequacy, most learners felt ICT resources sufficiently supported their learning, suggesting the need for urgent improvement in infrastructure.

Importantly, students expressed a heavy dependence on teachers and peers for ICT-related tasks. Most admitted they could not independently connect to Wi-Fi, use printers, or participate in online platforms like Microsoft Teams. These comments underscore a lack of digital literacy among students and the necessity for basic ICT training. Conversely, teachers demonstrated confidence and competence in using ICT tools, with the majority of them indicating that they possessed adequate ICT skills. Many used personal devices, projectors, and online platforms such as Microsoft Teams to enhance lesson delivery. Despite this, teachers acknowledged the need for ongoing training to keep up with evolving technologies.

Regarding actual ICT usage, students noted that while some schools used projectors and whiteboards weekly, others still relied on traditional chalkboards. Computer labs were occasionally used for video-based science simulations. Thus, while teachers show proficiency and enthusiasm for ICT integration, students remain largely dependent and undertrained. Bridging this gap through targeted student ICT training and infrastructure support is crucial for improving the digital learning experience in physical sciences. Responses from teachers are quoted below,

"Yes, well, most of the time I use my laptop and the school projector" (PHYSCT A1).

"I prefer to always use the whiteboard" (PHYSCT B1).

"I always take my students to the computer lab to watch science/experiment simulations" (PHYSCT C1).

"Yes, I usually conduct weekend lessons via Microsoft Teams" (PHYSCT D1).

"I use my Tablet most of the time to prepare my lessons" (PHYSCT E1).

Students also shared their joy when learning with ICT in the science classroom. One student narrated: *It was like magic when our teacher used a simulation to explain how atoms stick together. Reading or drawing alone could show me something I could never have imagined.*

This finding indicates that the use of digital tools in science teaching helps in the visualization of concepts.

4.3.3. Theme 3: Barriers to Integration

One of the most prominent issues was the students' lack of confidence in their own ICT skills. Nearly half of the respondents indicated a lack of confidence in using ICT for learning physical sciences. This lack of confidence was especially evident in Schools A, B, and E, where both teachers and students reported not knowing how to use ICT properly.

Teachers themselves shared similar frustrations. One teacher lamented, *"There is less ICT equipment in my school* (PHYSCT E1), while another explained that it *is difficult to teach physical sciences using ICT facilities because it requires more hands-on practical work than just the use of technology* (PHYSCT E1). Others highlighted spatial limitations and equipment shortages: *No laboratory for ICTs, space is very limited* (PHYSCT C1), and *the big challenge is that there are many students but only eight desktop computers working* (PHYSCT A1). Connectivity issues were also a major concern: *The huge challenge is connectivity; our WiFi connection is on and off* (PHYSCT A1), and *We have an ICT laboratory, but it has no computers* (PHYSCT B1).

These barriers clearly indicate that the schools in the O.R. Tambo Inland District are not adequately equipped with the ICT infrastructure required to effectively support the teaching and learning of physical sciences. Most students indicated that their access to personal ICT devices outside school was limited. They highlighted that a lack of electricity and competing responsibilities at home further reduced students' ability to engage with digital learning. Three students lamented: *At home, we do not have internet or a laptop. I only use my mom's phone sometimes when she is not using it.* (*PHYSCLC1*). *I do chores after school, and we do not have electricity at night. I cannot watch the science videos the teacher gives us.* (*PHYSCL B2*). *Even if teachers give us links to resources, many of us cannot afford data to open them.* (*PHYSCLA1*).

4.3.4. Theme 4: Strategies and Plans for Better Integrating ICT

When asked about the kind of support that could enhance ICT integration, both students and teachers offered practical and thoughtful strategies. Teachers proposed that the Department of Basic Education should provide comprehensive training workshops for teachers, improve access to modern ICT resources, and ensure alignment between ICT tools and the curriculum. They also suggested peer mentoring and the employment of technical support staff to address ICT issues in real time. One teacher explained:

"I always make sure I first demonstrate the steps of using the simulation tools in class, especially for practical topics like reaction rates. After that, I group students so they can assist each other before trying it on their own" (PHYSCTD2). This approach allows students to engage collaboratively, develop peer-assisted learning skills, and reduce anxiety associated with independent technology use.

Teachers echoed these sentiments. One suggested, *"I would appreciate it if teachers could be trained for ICT-based content"* (PHYSCT A1), while another stated, *"I suggest that the curriculum must be changed to align with the needs of ICT facilities"* (PHYSCT C1). Several emphasised the need for more specialised training: *"We should be trained in coding and robotics to acquire more ICT skills"* (PHYSCT D1), and *"Students must study ICT as a compulsory subject in schools"* (PHYSCT E1).

This implies that, while current conditions reflect a lack of readiness for full ICT integration, the proposed strategies, focused on teacher training, curriculum reform, improved infrastructure, and student support, present a strong foundation for transformation. If implemented effectively, these recommendations could significantly enhance ICT use in Physical Sciences education, ultimately promoting better learner engagement, improved understanding of scientific concepts, and higher academic achievement in the O.R. Tambo Inland District. The strategies suggested echo those of Lawrence (2022) and Torres-Madroñero, Torres-Madroñero, and Ruiz Botero (2020) which emphasise the importance of context-sensitive interventions. A collaborative, multi-stakeholder approach is needed to bridge the digital divide in rural science classrooms.

5. Discussion of Findings

This study examines the influence of ICT on the teaching and learning of physical sciences in rural high schools, with a particular emphasis on the O.R. Tambo Inland District in South Africa. Within the rural context, the study examines the findings in conjunction with the theories of TPACK and pertinent literature.

The first finding shows that ICT facilities at schools were generally scarce. Although some schools had access to fundamental ICT infrastructure, many lacked more advanced resources, such as smartboards, projectors, and specialised science software. This implies that teachers and students were not able to effectively integrate ICT into physical science teaching and learning, which was due to the disparity in ICT availability. The findings indicate that the availability of ICT facilities in the study area is insufficient to facilitate the widespread adoption of ICT in classrooms. The literature underscores the necessity of thorough planning and consideration when incorporating ICT into physical science instruction, as alluded to by Du Plessis and Letshwene (2020). According to Venketsamy and Hu (2022), in order to enhance learning outcomes, it is imperative to acquire ICT skills, and effectively utilising them is paramount.

The study further found that insufficient ICT availability hindered the full integration of technology into physical science education, thereby restricting the use of tools by teachers and students. This finding is in line with the studies by Park et al. (2021) and Papadimitropoulos et al. (2021). The transition to more interactive, personalised, and engaging learning experiences, which Zidny et al. (2020) proposed are facilitated by the implementation of multimedia materials, but were impeded by the dearth of access to ICT tools. In addition, Valverde-Berrocoso et al. (2021) emphasised that ICT enhances traditional instruction by facilitating flexible learning. Nevertheless, the O.R. Tambo Inland District schools have inadequate ICT infrastructure, impeding teachers from capitalising on these advantages, thereby exacerbating the discrepancies between the theoretical integration of ICT and its practical application in the classroom. In the same vein, Suleiman et al. (2020) emphasised that the successful integration of ICT necessitates both technological and pedagogical expertise. However, the findings suggest that a significant number of teachers were unable to develop these competencies due to a lack of access to the requisite tools. From a TPACK perspective, Akbulut, Çetin-Dindar, Küçük, and Şeşen (2020), the effective integration of ICT in physical sciences necessitates a sophisticated fusion of technological, pedagogical, and content knowledge, rather than merely fundamental TPACK. Teachers are unable to design learning experiences that are both interactive and scientifically accurate due to the absence of ICT tools, which impedes their ability to meaningfully connect their TPACK.

The second finding shows that the utilization of ICT among physical science teachers and students was minimal. Traditional teaching methods were primarily employed by teachers, frequently as a result of inadequate training or a lack of confidence in the use of ICT tools. In the same vein, students' engagement with ICT was primarily restricted to general applications, as opposed to subject-specific ones. This underutilization was further exacerbated by the insufficient availability of ICT resources, which impeded their regular use in the teaching and learning process. Effective ICT integration within the TPACK framework (Akbulut et al., 2020) necessitates the capacity to align technology use with both pedagogical strategies and subject content, in addition to technical proficiency (TK). The absence of TPACK development is indicated by the fact that a significant number of teachers continue to rely largely on traditional, textbook-centred instruction. Teachers' inadequate training and confidence suggest that they are incapable of effectively integrating technology into their instructional strategies, thereby limiting the potential for interactive, student-centred science instruction. The finding contrasts with the literature, which emphasises the critical role of ICT in improving the teaching and learning experience of physical science by allowing teachers to utilise tools such as simulations, virtual labs, and multimedia resources to simplify complex concepts, as suggested by Musokhonovna (2021) and Zidny et al. (2020). However, the finding is consistent with the findings of Azlan et al. (2020) and Venketsamy and Hu (2022), which indicate that a significant number of teachers employ ICT for routine tasks such as internet searches and presentations, rather than for active learning. Also, it was discovered that students' utilisation of ICT was primarily restricted to general applications, as opposed to subject-specific learning. This is in line with Molenda (2023) observation that ICT frequently prioritises administrative functions overactive learning, which is reflected in this underutilisation of ICT tools in these schools.

The third findings of this study highlight a number of critical factors that influence the effective use of ICT in physical science education, such as a lack of awareness or motivation among teachers and students, limited funding, poor internet connectivity, and inadequate teacher training. These challenges are consistent with the literature, which underscores that the successful integration of ICT in education is contingent upon the socio-cultural context, teacher competence, administrative support, and infrastructure availability (Anthonysamy et al., 2020; Valverde-Berrocoso et al., 2021). Inadequate teacher training was one of the primary challenges identified in the study, which resulted in a lack of confidence in the integration of ICT tools into the classroom. The literature emphasizes the need for teacher training to achieve proficiency in ICT competency, enabling teachers to effectively employ a variety of digital tools for teaching (Qazi et al., 2022). Ramsten, Martin, Dag, and Hammar (2018) underscored the significance of preparing teachers to effectively manage professional responsibilities, whereas Venketsamy and Hu (2022) contended that teachers' ICT proficiency could be enhanced through the development of positive motivation, computer literacy, and methodological skills.

The findings also revealed that schools were unable to acquire and maintain ICT infrastructure due to a lack of funding. Valverde-Berrocoso et al. (2021) emphasise the importance of robust ICT facilities for the successful integration of ICT in education, which is consistent with the finding. On the other hand, the procurement and maintenance of these resources were impeded by financial constraints in numerous schools, which hindered the full utilisation of ICT in physical science education for both students and teachers. This study confirmed that a significant number of teachers and students were unaware of or lacked motivation to incorporate ICT into physical science education. This is consistent with the literature, which indicates that teachers' attitudes towards ICT have a substantial impact on their propensity to incorporate digital tools into their classrooms (Qaddumi et al., 2021; Suleiman et al., 2020). In addition, the literature indicates that most teachers perceived ICT as an administrative burden rather than a learning instrument, which resulted in resistance and underutilisation (Junaidi, Hamuddin, Simangunsong, Rahman, & Tatum, 2020; Musokhonovna, 2021). The promotion of more proactive ICT adoption could be facilitated by addressing these misconceptions through awareness campaigns and training.

The third finding also exposes a number of interrelated challenges that impede the effective integration of ICT in physical sciences education in the selected high schools. These include a general lack of awareness or motivation among both teachers and students, weak internet connectivity, limited funding, and inadequate teacher training. The essential components of the TPACK framework are directly impacted by these challenges, which underscore the necessity of the intersection of TK, PK, and CK for the effective integration of ICT in teaching, the active role of teachers as designers of technology-enhanced learning, and provide a theoretical foundation for fostering TPACK development in teacher education (Koehler & Mishra, 2009) Teachers often encounter difficulties in effectively integrating these domains due to the lack of sufficient training and support.

Additionally, the potential to establish student-centred, engaging learning environments is reduced by inadequate teachers' motivation and students' lack of awareness of the importance of ICT. These results are consistent with the existing literature, which emphasises that the success of ICT in science education is contingent upon a variety of factors, including teacher competence, ongoing professional development, and systemic support (Anthonysamy et al., 2020; Valverde-Berrocoso et al., 2021).

The fourth and final finding of this study proposed strategies for enhancing the integration of ICT in physical science instruction that are consistent with the literature's recommendations for rural classrooms. The literature underscores the importance of professional development, curriculum development, stakeholder collaboration, and community engagement as critical strategies for promoting the effective utilization of ICT (Boateng & Marwanqana, 2024).

The study identified the necessity of consistent professional development programs to improve the skills and confidence of teachers in the effective use of ICT tools. This was one of the main strategies. This is corroborated by the literature, which emphasizes the importance of teacher training in the integration of ICT. Teachers may encounter difficulties in effectively employing ICT tools, which may restrict their influence on students' learning if they lack sufficient training. This disparity can be bridged through training programs that emphasize multimedia integration, digital literacy, and learning management systems (LMS) (Boateng & Marwanqana, 2024).

6. Conclusion

This study aimed to examine the contextual realities of ICT integration in rural physical sciences classrooms in South Africa, employing the TPACK framework. It utilized qualitative inquiry across five rural schools, involving 10 physical sciences teachers and 10 learners, to assess the availability and utilization of ICT facilities, factors influencing ICT usage, and strategies to enhance integration efforts. The findings indicate that the allocation of ICT resources among high schools is irregular and largely insufficient. Digital tools are often underutilized due to limited infrastructure, unstable internet connectivity, and inadequate ongoing technical support. Teachers reported restricted access to devices and educational software, while students demonstrated significant dependence on teachers. Several factors affecting ICT integration were identified, including teacher confidence and technological ability, infrastructure limitations, students' digital skills, and broader socio-economic challenges typical of rural educational environments. Additionally, institutional support, access to professional development opportunities, and curricular mandates substantially impacted teachers' capacity to incorporate ICT into their practice. The study proposed context-specific solutions to facilitate improved ICT integration, focusing on in-service teacher training based on the TPACK framework, learner-centered digital literacy initiatives, and the creation of collaborative learning networks for teachers to exchange digital teaching methodologies. Furthermore, investment in infrastructure was deemed essential for enabling consistent ICT utilization in education. The study underscores the importance of contextualizing ICT integration initiatives within the realities of rural educational environments. Successful adoption of digital technologies in physical sciences education depends on both access and the alignment of technology with pedagogical methods and content knowledge. Therefore, capacity-building initiatives, resource allocation, and policy support must be specifically tailored to address the unique challenges and opportunities of rural schools to promote meaningful and sustainable ICT integration in science teaching.

7. Recommendations

Based on the findings of this study, the following recommendations are proposed to strengthen ICT integration in physical sciences education within rural South African classrooms:

7.1. For Teachers

Teachers should undergo comprehensive professional development focused on:

- ICT Basics and Digital Literacy Training in basic computer skills, Microsoft Office applications, digital safety, and responsible use of technology.
- Subject-specific integration workshops on incorporating simulations, virtual labs, and science-specific online resources (e.g., PhET, NASA STEM).
- Interactive Teaching Strategies: Hands-on use of digital whiteboards, multimedia tools, and the development of ICT-based lesson plans.
- Ongoing Support and Resources: Teachers must be equipped with appropriate digital tools and receive continuous administrative and technical support to ensure effective ICT implementation.

7.2. For Students

Students should be trained in using ICT tools essential for physical sciences learning, writing and formatting lab reports, data analysis, graph plotting, interpreting scientific results, managing and organizing datasets and laboratory information, and building their competencies to enhance both academic performance and digital readiness.

7.3. For the Department of Basic Education (DBE)

The DBE should take a strategic and equitable approach by:

- Providing ICT infrastructure to all schools with updated computers, projectors, whiteboards, and reliable internet connectivity.
- Equipping teachers, ensuring all teachers receive a personal ICT device pre-loaded with science teaching software.
- Expanding Learner Access by distributing subsidised digital devices and educational content for student use in and out of school.
- Creating central resource hubs for developing online platforms for accessing open educational resources, simulations, and multilingual content.
- Monitoring and Evaluation to establish systems for evaluating the use and effectiveness of ICT resources and gathering feedback for continuous improvement.

7.4. For Future Research

Further research is recommended to:

- Conduct longitudinal studies on ICT's long-term impact on learning physical sciences in rural schools.
- Undertake qualitative case studies exploring teacher and learner perspectives on ICT use in physical science classrooms.
- Implement experimental research comparing ICT-enhanced and traditional methods in science classrooms.
- Apply mixed methods approaches to assess teacher training and ICT competency.
- Perform policy and infrastructure audits to evaluate ICT policy implementation and identify gaps in school ICT capacity.

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