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Technology Integration in Grade 11 Physical Sciences: Resources, Infrastructure and Teacher Agency

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Abstract: The growing importance of technology in the teaching and learning of Physical Sciences is widely recognised; however, teachers face significant challenges that hinder its implementation. Guided by constructivist learning theory, this study examined the challenges teachers encounter in adopting and integrating educational technologies into the teaching of Grade 11 Physical Sciences in South African public schools. A qualitative exploratory design was employed to collect data through semi-structured interviews with six Grade 11 teachers at public secondary schools in the Tshwane South District, and the data were analysed using thematic analysis. The findings revealed critical and ongoing challenges, including limited infrastructure and connectivity, insufficient professional development, time constraints, and gaps in teachers' digital competencies. The findings also highlight the potential of technology to enhance learner engagement and conceptual understanding in the Physical Sciences. Additionally, teachers identified self-directed learning, peer collaboration, and external assistance as effective methods for adapting and integrating technology into classroom practice. This study contributes to the existing body of knowledge by providing qualitative insights into the challenges that Grade 11 Physical Science teachers face when adopting and integrating technology in resource-constrained South African public schools. Practical implications include ongoing professional development, equitable allocation of technological equipment, and sufficient network access to facilitate teachers' integration of classroom technology in public schools. Future research should investigate subject-specific approaches to technology integration in the Physical Sciences to enhance comprehension, learner engagement, and curriculum implementation in these unique educational contexts.

Keywords: Connectivity and infrastructure, physical sciences, professional development, teaching, technology integration, technology.

1. Introduction

The adoption and integration of technology in education have become increasingly critical for enhancing teaching and learning in the Physical Sciences. However, teachers continue to face challenges that hinder implementation. Technology influences most aspects of our lives, and educational processes must continually gather and integrate new data, resources, and technological systems (Ansari et al., 2024; Francom et al., 2021). Access to essential hardware, reliable connectivity, and technical support is fundamental to the successful adoption of technology in education. Without these, secondary school teachers encounter difficulties in effective implementation (Pearce, 2022). Akram et al. (2022) and Francom (2020) concur with Pearce (2022) in arguing that, despite considerable expenditure on technology in educational infrastructure and the widespread availability of digital tools, teachers continue to face significant challenges in effectively integrating these technologies into their teaching practice.

In both rural and urban Grade 11 settings in Qatar and Colombia, technology-related barriers have been recognised, alongside challenges at the school and teaching levels, with technological limitations adversely affecting Science, Technology, Engineering, and Mathematics (STEM)

education (Sellami et al., 2024). In Morocco's secondary and higher education sectors, infrastructural and organisational challenges persistently impede distance learning and ICT-enhanced teaching, particularly concerning access to digital platforms and equipment (Outoukarte et al., 2023). Furthermore, these limitations are most pronounced in Grade 11, where high-stakes examinations and the demands of the curriculum necessitate reliable technology to facilitate inquiry and interactive learning.

The significant global transformations resulting from advancements in IICT and the COVID-19 pandemic have compelled numerous governments to recognise that traditional, content-based educational approaches are insufficient to equip learners with the knowledge, skills, and practices necessary to thrive in the 21st century (Naidoo, 2026). The COVID-19 pandemic underscored both the capabilities and constraints of technology in education, as schools worldwide shifted to remote learning, revealing enduring challenges that impede effective technology integration (Christopoulos & Sprangers, 2021; Francom et al., 2021). The experiences during the pandemic highlight the resilience and vulnerability of technology-enabled Grade 11 teaching, emphasising the necessity for flexible pedagogies, effective assessment strategies, and continuous professional development for teachers in online and hybrid environments (Li, 2023; Kekeba et al., 2025). Grade 11 represents a pivotal phase in secondary education, as learners prepare for the transition to post-secondary education and are expected to cultivate advanced, context-specific technology skills. Nonetheless, a clear research gap exists regarding the challenges teachers face in adopting technology in Grade 11 classrooms. Most studies focus on more generalised, less content-specific K-12 or secondary school environments (Francom et al., 2021) and neglect the unique curriculum demands and assessment pressures specific to Grade 11.

Previous studies conducted in South Africa (Mnisi et al., 2024; Naidoo, 2026; Ahiaku et al., 2025) have identified challenges such as infrastructure limitations, inadequate technological resources, and teacher preparedness. However, these studies provide limited insight into how these challenges influence technology integration within Grade 11 Physical Sciences classrooms. Furthermore, insufficient attention has been paid to how resource allocation practices, infrastructure constraints, and teacher agency interact within subject-specific teaching environments. This study addresses these gaps by examining the challenges of technology integration and teacher responses within Grade 11 Physical Sciences classrooms in the Tshwane South District. It offers thorough and contextually relevant insights into the integration of technology in education. The study aimed to address the following research questions:

- What are the challenges of integrating technology into the teaching of Grade 11 Physical Sciences?
- How do Grade 11 Physical Sciences teachers respond to the challenges associated with technology integration?

The paper contributes to the existing body of knowledge by offering subject-specific insights into the challenges faced by teachers when integrating educational technologies in Grade 11 Physical Sciences classrooms. It elucidates the interconnected roles of resource allocation, infrastructure readiness, and teacher agency in shaping technology integration practices within South African public secondary schools. The paper is organised into several sections: a review of the literature on technology integration in education; a theoretical framework; a methodology; the presentation of thematic findings; a discussion of the findings in relation to the existing literature; and a conclusion that outlines recommendations, implications for practice, and directions for future research.

2. Literature Review

The initial technology employed in education was audiovisual media, which emerged in the early twentieth century. Since then, the role of technology in education has evolved significantly with the

introduction of computers and internet-based learning environments (Saettler, 2004). The term "technology in education" encompasses the application of tools, technologies, procedures, resources, and strategies aimed at enhancing learning experiences in both formal and informal contexts (Huang et al., 2019). Technology is characterised as the application of information, skills, and resources to address human needs and desires, as well as to develop practical solutions to problems, all while taking into account social and environmental considerations (Department of Basic Education [DBE], 2011). Classroom practices, along with the availability and utilisation of ICT resources, significantly influence the integration of technology within educational settings. Research on technology education and ICT integration reveals that, despite the accessibility of equipment, teachers' proficiency in ICT and the integration of ICT into pedagogical approaches differ by subject area, highlighting the need for targeted professional development and curricular alignment (Kekeba et al., 2025; Taole, 2024; Sharif & Khan, 2023).

2.1 Teaching practices and classroom interactions

Teachers encounter several practice-related challenges when incorporating technology in education, which frequently influence the extent to which pedagogical objectives are realised in classroom settings. Qualitative evidence indicates that although teachers acknowledge the benefits of technology in learning, their teaching methods often remain conventional due to limitations such as time constraints, substantial workloads, and diminished confidence, especially in Grade 11, when curriculum requirements are rigorous (Qurban & Mohammed, 2023). In high-stakes subjects such as English, teachers' attempts to implement communicative and interactive methods are frequently hindered by assessment frameworks that emphasise grammar and textbook-based teaching, consequently restricting the meaningful integration of technology (Karataş et al., 2024). However, integrating technology through interactive tools and simulations can significantly improve learners' comprehension, particularly when difficult concepts are explained visually and through practical demonstrations on platforms like YouTube. These techniques can enhance challenging textbook material and facilitate improved learner outcomes.

In STEM contexts, the effective implementation of inquiry- and project-based technological methods in education seems contingent upon proficient classroom management and the availability of collaborative support systems among teachers and learners (Sellami et al., 2024; Al Sharoufi, 2022). While technology provides opportunities to enhance learning, its effective integration is influenced by assessment requirements, pedagogical coherence, and the classroom environment. Thus, the teaching potential of technology in education is broadly recognised, its practical implementation is inconsistent and contingent on specific contexts across various subject areas.

2.2 Infrastructure, access and resources as prerequisites for the adoption of technology in education

Insufficient infrastructure constantly limits teachers' capacity to effectively and sustainably integrate technology in education, especially in Grade 11. In various geographical contexts, limitations in hardware, software, internet connectivity, and power reliability jointly hinder implementation endeavours. Evidence from Ethiopian secondary schools indicates low and inconsistent integration of ICT, primarily due to inadequate connectivity and restricted access to computers, with significant discrepancies between private and public schools (Molla & Seyoum, 2022). In Namibia, teachers identify unreliable internet connectivity, inadequate technical support, and limited resource availability as significant barriers to integrating ICT into secondary curricula, particularly in Grade 11 mathematics (Chirimbana et al., 2024).

Nonetheless, these issues are not limited to African contexts, as research from Southeast Asia and the Middle East substantiates the systemic nature of infrastructure-related limitations. In Oman, inadequate ICT infrastructure and constrained internet connectivity are recognised as primary

challenges to adoption, especially in private primary schools, with repercussions extending to secondary education, where resources are frequently shared or strained (Qurban & Mohammed, 2023). In Cambodia, rural upper-secondary teachers also indicate inadequate infrastructure and technical assistance, which adversely affect preparedness and the regular utilisation of technology in the classroom (Pang et al., 2022). This illustrates widespread global issues related to the digital divide, where disparities between rural and urban schools, along with variations in institutional resources, persistently influence the extent and quality of technology in Grade 11 classrooms (Pang et al., 2022; Saputra et al., 2024).

Thus, infrastructural sufficiency becomes a prerequisite for successful technological integration, influencing both accessibility and the depth and quality of educational application. In the absence of reliable devices, consistent connectivity, and continuous technical assistance, teachers face a significant challenge in integrating technology into teaching and learning methodologies. This consequently restricts opportunities for advanced teaching methods often associated with Grade 11 curricula, including higher-order inquiry, STEM-based experimentation, and language-integrated digital tasks. Consequently, infrastructural limitations continue to affect both the teaching process and learning engagement, as well as assessment methodologies, thus perpetuating disparities in educational experiences across various contexts (Chirimbana et al., 2024; Molla & Seyoum, 2022; Pang et al., 2022; Qurban & Mohammed, 2023; Saputra et al., 2024).

2.3 Teacher competence, confidence and professional development requirements

ICT proficiency and ongoing professional development (PD) are widely seen as essential to teachers' ability and readiness to integrate technology in education in Grade 11 classrooms. Nevertheless, the literature underscores a continual disparity between the accessibility of infrastructure and teachers' capacity to utilise it proficiently. Cabunoc and Ubayubay (2024) contend that ICT proficiency is influenced by variables such as age, experience and attitudes, while structural impediments, including insufficient manpower, ambiguous policies and inadequate facilities, further hinder effective integration. Pang et al. (2022) note that despite teachers' favourable attitudes towards ICT, inadequate training and low skill levels hinder their ability to implement ICT, especially in resource-limited rural settings.

However, research from European and Nordic contexts presents a more nuanced viewpoint by highlighting teacher agency and professional capital as catalysts for digitisation (Kupiainen, 2022). This indicates that although autonomy is essential, it requires support through focused and continuous PD. Data from Malaysian secondary schools substantiate this assertion, as persistent challenges, such as time limitations, insufficient competence, and swiftly advancing technologies, impede effective integration (Sulaiman et al., 2024). In many settings, there is consensus that singular training is inadequate. Thus, the literature advocates for a transition to enduring, context-specific PD that enhances both general digital proficiency and subject-specific pedagogical integration. Significantly, PD is most efficacious when integrated into teachers' daily practices, connected with curricular requirements and attuned to workload challenges, especially during the academically rigorous Grade 11 year.

3. Theoretical Framework

This study is guided by constructivist learning theory, which asserts that learners gain knowledge through their experiences (Liangshi, 2025). Constructivist learning theory, as articulated in this study, is rooted in Piaget's theory, which focuses on several cognitive development stages, during which children build knowledge through exploration and social interaction, while Vygotsky highlights the importance of social interaction and cultural tools in learning, such as language, computers or chalkboards (Waite-Stupiansky, 2022). Technologies used in education, such as simulations, virtual laboratories and collaborative platforms, align with this perspective as they offer

interactive environments for learners to explore concepts, modify variables and assess their comprehension. In a classroom setting, learning is influenced by prior knowledge, and digital tools facilitate personalised education by allowing learners to engage with content at their own pace and at their level of comprehension. This facilitates more individualised learning experiences, which are crucial in different Grade 11 classrooms. Effective integration relies on teachers' proficiency in designing technology-enhanced activities that foster active engagement and knowledge construction rather than employing technology for passive information delivery (Mishra, 2023). Consequently, constructivism offers a robust theoretical framework for understanding the rationale and methodology for integrating technology.

Moreover, constructivism emphasises social engagement, scaffolding and real-world learning as fundamental components, which are augmented by technological integration. Vygotsky's concept of the Zone of Proximal Development underscores that learners gain from directed assistance when undertaking demanding tasks (Zajda, 2021; Khushk et al., 2022). Digital tools, such as learning management systems, enhance engagement and the co-construction of knowledge among learners. Furthermore, technology facilitates the development of a genuine, real-world learning environment through simulations and project-based activities, which are fundamental to constructivist education (Harasim, 2017). This literature indicates that effective technology integration requires teachers to function as facilitators, providing appropriate scaffolding and directing learners' interactions with digital tools (Winitzky et al., 2005; Zajda, 2021). Challenges such as insufficient teacher expertise, time limitations and resource scarcity may hinder this process. However, when these problems are mitigated, technology-supported constructivist methodologies can improve cooperation, critical thinking and profound comprehension in Grade 11 classes.

4. Methodology

This study employed a qualitative exploratory design (Creswell & Creswell, 2018) to examine the challenges Grade 11 teachers face in adopting and integrating technology in education and to explore ways to improve this integration in practice. An interpretivist paradigm, using an exploratory multiple-case study design, guided the study, enabling an in-depth understanding within natural classroom contexts (Saunders et al., 2019). These approaches enabled the researcher to engage closely with Grade 11 Physical Science teachers, uncovering diverse experiences and meanings of technology use in teaching. Consequently, the study generated rich, context-specific insights that would not have been attainable through quantitative methods or surveys alone.

This study focused on Grade 11 Physical Sciences teachers employed at public secondary schools in the Tshwane South District of Gauteng. Participants were selected through purposive sampling because they could provide rich information regarding the integration of educational technology in Grade 11 Physical Sciences classrooms (Creswell & Creswell, 2018). To be included in the study, participants had to be qualified Physical Sciences teachers, actively teaching Grade 11 Physical Sciences, and have experience with, or attempted to use, educational technologies in their teaching practice. Permission to conduct the study was obtained from the relevant education authorities and school principals. Schools were approached through formal communication with school management teams, after which eligible teachers were invited to participate voluntarily in the study.

The selection of Grade 11 teachers was considered appropriate because Grade 11 serves as a critical preparation year for Grade 12 and plays an important role in learners' readiness for the National Senior Certificate examinations. Furthermore, Physical Sciences teachers often utilise educational technologies such as simulations, virtual laboratories, scientific visualisations, and data analysis tools to support the teaching of complex scientific concepts. Consistent with the objectives of this study, recent research underscores the need to collect data from schools to understand contemporary ICT usage trends and the issues teachers encounter in practice (Mnisi et al., 2024). Participants were selected for their subject competence and practical teaching experience, which are significant factors

in qualitative educational research on teacher practice and expertise (Anderson & Taner, 2023). Permission to conduct the study was obtained from the relevant education authorities and school principals. Schools were approached through formal communication with school management teams, after which eligible teachers were invited to participate voluntarily in the study. The participants had 3 to 15 years of experience teaching Grade 11 Physical Sciences, a comprehensive understanding of the curriculum, and direct exposure to the opportunities and challenges in their teaching environments. Consequently, six teachers were purposefully chosen from six public schools in the Tshwane South District of the Gauteng Province.

4.1 Data collection

Six Grade 11 Physical Science teachers from different public schools in the Tshwane South District of Gauteng participated in this study. The semi-structured interviews were conducted between March and April 2026 at the participants' schools during breaks or a free period. The interviews were conducted in English, as it was the preferred language of all participants. The interviews lasted between 15 and 30 minutes and were audio-recorded with the participants' consent. The duration was considered sufficient because the interviews focused on a specific research topic and yielded rich, relevant data on teachers' experiences of integrating educational technology in Grade 11 Physical Sciences classrooms. The audio recordings were transcribed verbatim by the researcher, and the transcripts were then reviewed against the recordings to ensure accuracy. Data collection continued until sufficient depth of information had been obtained to address the research question. The fact that no substantially new themes emerged from the interviews indicated that data saturation had been reached. An interview guide ensured consistency across interviews while allowing participants the flexibility to elaborate on their experiences. Although not the primary focus, the school context was acknowledged as a factor influencing technology integration, and the study relied on participants' ability and willingness to provide relevant insights to address the research question. The participants were selected from schools representing varied contexts, levels of resourcing and geographic locations within the province. To ensure their anonymity, participants are identified by number, from Participant 1 (P1) to Participant 6 (P6), and school names were replaced with pseudonyms (School 1 to School 6). Table 1 presents the demographic and contextual profiles of each participant, along with a brief discussion of the sample characteristics.

Table 1: *Participants' Details*

Participant	Gender	Qualifications	Schools (pseudonym)	School context
P1	Male	Master of Education in Science Education	School 1	Township public secondary school
P2	Female	Postgraduate Certificate in Education (PGCE). Currently studying for an Honours degree in Education.	School 2	Technical secondary school (township context)
P3	Male	Diploma in Education	School 3	Former Model C high school
P4	Female	Secondary Teacher Diploma	School 4	Technical secondary school
P5	Male	Honours degree: Mathematics Education	School 5	Former Model C high school
P6	Female	Bachelor of Education (BEd)	School 6	Public secondary school

Table 1 presents information on the six Physical Science teachers (P1–P6) across six different secondary school settings. The participants were purposively selected from public schools in the Tshwane South District. The sample was considered sufficient because data saturation was achieved after interviewing the sixth participant, as no new information or additional themes emerged from

the interviews. The schools vary from township schools to public and technical schools, to well-equipped former Model C schools, indicating significant contextual variety. The teachers' qualification profiles highlight trends in the utilisation of educational technologies.

4.2 Data analysis

The data collected through semi-structured interviews were thematically analysed as described by Braun and Clarke (2006). Thematic analysis is a foundational method for identifying, analysing and reporting patterns (themes) within qualitative data (Braun & Clarke, 2006). It offers a flexible, accessible and theoretically adaptable approach that is well-suited to studies operating within an interpretivist paradigm and a constructivist theoretical framework. This method was selected because it accommodates an inductive, data-driven orientation that allows themes to emerge from the participants' own words, rather than being imposed by preconceived theoretical categories.

In imitation of Braun and Clarke (2006), six recursive phases of thematic analysis are outlined: (1) familiarising oneself with the data, (2) generating initial codes, (3) searching for themes, (4) reviewing themes, (5) defining and naming themes, and (6) producing the report. In this study, the familiarisation process involved multiple rounds of engagement with data documents: six interview transcripts, each read in its entirety at least three times before any coding began. Then, in phase 2, the researcher systematically worked through each data document, identifying and labelling meaningful segments of text with descriptive codes. Phase 3 involved sorting the codes into broader groupings that represented potential themes. Phase 4 involved a two-level review of the candidate themes, as recommended by Braun and Clarke (2006). The researcher reread all the coded extracts collated under each theme and assessed whether they formed a coherent, internally consistent pattern. Where codes did not fit, they were either relocated to a more suitable theme or retained as sub-themes within a broader category.

In phase 5, each theme was refined, defined and named to capture its core analytical contribution. Braun and Clarke (2006) advise that the name of each theme should be concise, punchy and immediately give the reader a sense of what the theme is about. In this study, the theme names were crafted to be both descriptive and interpretive. The final phase involved writing the analysis as a coherent, evidence-based account that goes beyond description to make an argument in relation to the research question (Braun & Clarke, 2006). To establish trustworthiness, perceptions were corroborated through. For example, each time teachers made statements during the interviews, their statements were analysed to corroborate the interaction. After the interview transcripts had been consolidated, they were distributed to the participants, who checked them and confirmed that they accurately reflected their ideas.

4.3 Ethical consideration

The study adhered to the institution's ethical research requirements. Participants were informed about the purpose and procedures of the study, assured of confidentiality, and advised of their right to withdraw at any time. Written informed consent was obtained from all participants. Ethical clearance was granted by the institution's Professional Research Ethics Committee prior to the commencement of the study, and by the Gauteng Department of Education (Ref #: 7914 and 2025/531).

5. Presentation of Findings

The following section presents the study's findings on the challenges of integrating technology into teaching in the Grade 11 Physical Sciences classroom. The findings are organised according to three themes that emerged from the interview data: (1) limited and uneven distribution of resources, (2) connectivity and infrastructure constraints, and (3) uneven access to professional development and

support. These themes reflect participants' experiences of integrating technology into their teaching practice. Participants' verbatim quotations are used to illustrate and substantiate the findings.

5.1 Limited and uneven distribution of resources

The most striking finding under this theme was the uneven distribution of technological resources across and within schools. Participants from township or under-resourced schools described a reality in which technology is scarce, shared, and often reserved for the most senior grade levels.

P1 provided a detailed account of the resource hierarchy within the school:

> "*At this moment, as limited as our resources are, the technology that is used is only available for the Grade 12s. We have smart boards in Grade 12, and Grade 11s sometimes take classes there to simulate some lessons. But in the Grade 11 classes, it is only cellphones and sometimes a projector.*"

The consequence of this scarcity was that face-to-face teaching remained the dominant mode of delivery. P1 highlighted this limitation, stating that:

> "*If there is anything we need to simulate, we take a projector there. But that is rare. Mostly it is face-to-face contact teaching.*"

Participants indicated that limited access to technological resources restricted the frequency with which technology could be incorporated into classroom activities. In some cases, available technologies were shared across multiple classes, which reduced teachers' opportunities to use them consistently during lessons.

P2 echoed a similar experience, situating it within the context of township schooling, where resource constraints are more pronounced. The participant explained that limited access to technological tools poses a major challenge, noting that devices are often insufficient and must be shared among multiple teachers, thereby restricting consistent use in teaching. As P2 stated:

> "*The challenge is a lack of resources. The technological tools we need are often insufficient in our schools, especially township schools. You might receive one device that is shared between three different teachers. Sometimes when I need to use it, another teacher is already using it.*"

Additionally, the participant also noted the prioritisation of senior grades, particularly Grade 12, due to examination pressure.

> "*In our school, we have six smart boards, but that is not enough. We have prioritised Grade 12 learners to have smart boards in their classes, and more recently, Grade 11 classes also have them. Grades below that do not.*"

Participants highlighted that resource shortages were frequently described in relation to the availability of smart boards, projectors and other digital technologies. Participants reported that the allocation of these resources often differed across grades and schools, influencing how and when technology could be used during teaching.

5.2 Connectivity and infrastructure constraints

Even where hardware was available, connectivity emerged as a significant barrier to effective technology integration. P1 stated that Wi-Fi access effectively excludes teachers from routine internet-dependent technology use:

> "*The school's Wi-Fi is limited to management. Teachers cannot even log on to YouTube.*"

Similarly, despite being in a relatively well-resourced school, P6 identified bandwidth limitations as a practical challenge when large numbers of learners attempt to access online platforms

simultaneously. The participant explained that platforms such as Siyavula become difficult to use due to slow connectivity:

> *"The Wi-Fi is weak, and when we want to use Siyavula, for instance, or when learners try to log in simultaneously, the Wi-Fi struggles to support that many connections at once and becomes very slow."*

Participants consistently described internet connectivity as unreliable, regardless of whether technological devices were available. Slow internet speeds and restricted access limited the use of online platforms and digital learning resources during lessons. P4 highlighted practical connectivity challenges in equipment setup, noting that delays often occur when connecting the projector to a laptop during lessons. As the participant explained.

> *"Sometimes connecting the projector to the laptop can be challenging and time-consuming. It requires setting up in advance before learners arrive; otherwise, attempting to connect in front of the class causes delays, particularly for me."*

When asked how such challenges are addressed, the participant stated:

> *"That one is beyond our control. If it is down, it is down; there is nothing we can do."*

Participants described these connectivity and technical challenges as factors that disrupted lesson flow and reduced opportunities to incorporate technology into teaching activities.

5.3 Uneven Access to Professional Development and Support

Participants reported varying experiences regarding professional development and support for technology integration. While some teachers reported having access to training opportunities and institutional support, others relied primarily on self-directed learning and personal initiative to develop their technological skills.

P4 described the absence of formal training opportunities:

> *"The school does not conduct formal training for us, so you have to research things yourself on the internet and figure out how things work. So essentially, I overcome challenges through my own independent research."*

P1 similarly explained:

> *"In terms of guiding learners on what material to access on the internet, I learnt that on my own, not from the employer, because I am the one responsible for the subject. I tell my learners not to use videos from America, because we are following the CAPS curriculum, and they should not confuse themselves."*

P5 described school-based and external training initiatives:

> *"At school level, we run our own internal training, for example, on Google Classroom. We also had AI training, and currently, some of us have enrolled in free AI courses on the Microsoft platform. There are also ChatGPT courses available, and some colleagues have already earned certificates from those."*

The findings show differences in the availability of professional development across schools. Some participants described receiving structured support from the DBE (2015), ICT specialists, and colleagues, whereas others reported relying mainly on self-directed learning, online resources, and independent exploration to develop the skills required for technology integration.

Taken together, the findings indicate that teachers experienced challenges related to resource availability, connectivity and infrastructure limitations, and uneven access to professional development and support. Participants also described different ways of responding to these

challenges, including sharing resources, engaging in self-directed learning, and making use of available support structures within their schools and from the Department of Basic Education.

6. Discussion of Findings

This study's qualitative findings highlight key challenges that hinder teachers' ability to integrate technology into the teaching of Physical Sciences. The discussion focuses on how resource allocation, infrastructure constraints and professional development opportunities shape teachers' use of technology in the classroom. The findings are interpreted in relation to existing literature and Constructivist Learning Theory, which emphasises active learning, exploration, inquiry, and the construction of knowledge through meaningful learning experiences.

Participants' accounts suggest that access to technological resources was uneven across schools and grade levels, with Grade 12 classes often receiving priority access. Similar findings have been reported in previous studies, which identify limited access to technological resources as a persistent barrier to effective technology integration in schools (Naidoo & Govender, 2022; Howard et al., 2021). However, the present study suggests that the challenge extends beyond resource shortages, highlighting how decisions about allocating available technologies can influence opportunities for technology integration.

From a constructivist perspective, technological tools provide learners with opportunities to engage actively with content through exploration, visualisation, and inquiry. When access to these tools is limited or inconsistent, opportunities for interactive and learner-centred learning may also be reduced. In Physical Sciences, technologies such as simulations, virtual laboratories, and multimedia resources can support the visualisation of scientific processes and concepts that are not easily observed in real-world settings. Consequently, unequal access to technological resources may affect learners' opportunities to engage in learning experiences that promote conceptual understanding and knowledge construction.

A particularly important finding was the prioritisation of technological resources for Grade 12 classes. Although participants acknowledged the pressures associated with preparing learners for high-stakes examinations, directing available technologies towards senior grades often limited opportunities for Grade 11 learners to engage with technology-supported learning activities. This finding is consistent with previous research showing that access to technology, institutional support, and resource availability influence successful technology integration (Bećirović, 2023). Similarly, Ansari et al. (2024) argue that inadequate technological support systems can constrain teachers' ability to integrate technology meaningfully into their teaching practice.

This study adds further insight by showing that access to technology is influenced not only by the availability of resources but also by how those resources are distributed within schools. While previous studies have largely focused on shortages of technological resources, participants' experiences suggest that allocation practices may be equally important in shaping technology integration. The prioritisation of Grade 12 classes appeared to reduce opportunities for Grade 11 learners to engage with activities that support exploration, visualisation, and inquiry, all of which are central to constructivist learning. In Physical Sciences, where many concepts are abstract and require visual representation, limited access to digital technologies may restrict opportunities for meaningful knowledge construction.

In South Africa, the White Paper on e-Education (2004) and the DBE's ICT Integration Strategy (DBE, 2015) advocate equitable access to digital resources, skills development, and improved technological infrastructure. Nevertheless, participants' experiences suggest that access to technological resources remains uneven, particularly in under-resourced schools. Research indicates that structural

inequalities in education are often reflected in unequal access to educational technologies (Macgilchrist et al., 2024). The experiences shared by participants support this view, illustrating how disparities in access continue to shape teachers' ability to integrate technology into classroom practice. These disparities reflect broader concerns about the digital divide, in which socioeconomic inequalities shape access to technology and learning opportunities (Safidon, 2024; Macgilchrist et al., 2024). Furthermore, inequalities in access to devices, internet connectivity, and digital resources continue to disadvantage learners in under-resourced contexts, contributing to unequal educational opportunities (Eden et al., 2024; Naidoo, 2026).

Taken together, the findings suggest that improving technology integration requires more than increasing the number of technological resources available in schools. The study highlights the importance of considering how resources are allocated across grade levels, as allocation practices can influence the extent to which learners benefit from technology-enhanced teaching and learning. Ensuring equitable access to digital technologies may expand opportunities for Grade 11 Physical Sciences learners to engage with simulations, virtual laboratories, and other learning experiences that support deeper conceptual understanding.

6.1 Connectivity and infrastructure constraints

Although some schools had access to technological devices, participants frequently described connectivity and infrastructure-related challenges that limited the effective use of these devices. Weak internet connectivity, restricted Wi-Fi access, and technical difficulties reduced opportunities to use online platforms and digital learning resources during lessons.

These findings are consistent with previous studies that identify connectivity and infrastructure limitations as ongoing barriers to technology integration in schools (Naidoo & Govender, 2022; Akram et al., 2022). However, the findings of the present study suggest that the availability of technological devices alone does not guarantee meaningful technology integration. Participants' experiences indicate that access to digital resources is closely tied to the quality and reliability of the infrastructure that supports their use.

From a constructivist perspective, technology can facilitate active learning by providing learners with opportunities to explore, investigate, and interact with information. When internet access is unreliable, teachers may struggle to use digital resources that support inquiry-based learning and learner engagement. In the context of Physical Sciences, technologies such as simulations, instructional videos, virtual experiments, and online learning platforms can enhance learners' understanding of complex and abstract scientific concepts. Limited connectivity, therefore, reduces opportunities to engage in technology-supported activities that promote exploration and conceptual understanding.

Participants also described practical challenges associated with setting up and connecting technological equipment during lessons. These difficulties often resulted in delays and disruptions that affected the flow of teaching and learning. Beyond limiting access to online resources, infrastructure-related challenges influenced teachers' decisions about whether to incorporate technology into lessons at all. As a result, teachers sometimes relied on more traditional teaching approaches when technological systems were unavailable or unreliable.

An important insight emerging from these findings is that technology integration depends not only on teachers' willingness to use digital tools but also on the infrastructure available to support their use. While teachers expressed positive attitudes towards technology integration, unreliable connectivity and technical challenges often constrained their ability to implement technology-enhanced teaching strategies effectively. In Physical Sciences classrooms, where digital tools can support the visualisation of abstract concepts and scientific processes, these limitations may reduce learners' opportunities to engage in meaningful, interactive learning experiences.

6.2 Professional development and teacher agency

The findings showed that teachers frequently engaged in self-directed learning, peer collaboration, and professional development opportunities to improve their technological competencies. This finding aligns with previous studies suggesting that continuous professional development enhances teachers' confidence and ability to integrate technology into teaching (Tondeur et al., 2017; Scherer et al., 2021). From a constructivist perspective, teachers play a facilitative role in supporting learners' knowledge construction. To fulfil this role effectively within digitally enhanced learning environments, teachers require both technological and pedagogical competencies. The proactive efforts demonstrated by participants suggest that teachers recognise the importance of developing these competencies to create meaningful learning experiences for learners.

The advantages of professional development for teachers are significant. Prior research has shown the benefits of teacher development focused on improving teaching through technology in education. Figure 1 illustrates the professional development structure as a fundamental support system for integrating technology in education among Grade 11 Physical Sciences teachers. It illustrates how multiple settings and mechanisms of professional development enhance teacher competency, classroom application and learning outcomes.

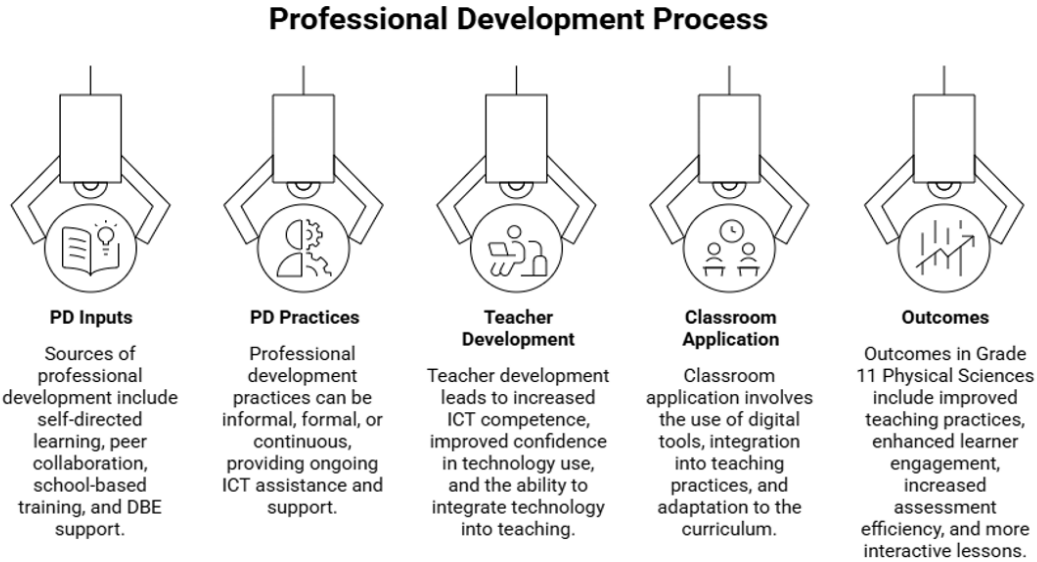


Figure 1: *Professional development for technology integration in grade 11 [**Source**: The Author]*

In the absence of formal training, participants demonstrated self-directed professional development, as illustrated in figure 1, with teachers independently enhancing their technological competencies. Participants reported that they depended on self-motivation and digital resources to acquire skills for integrating technology into their teaching practices, supporting Deng and El Hag's (2024) claim that schools must offer sufficient training while addressing educational inequalities. Nevertheless, certain participants indicated greater proactive involvement through school-based projects and external online courses, particularly those centred on new technologies such as artificial intelligence. Professional development is crucial for equipping teachers with the necessary expertise and skills to improve teaching and successfully integrate technology (Verawati & Nisrina, 2025). Moreover, the DBE (2015) assists through training programmes and facilitators, thereby enhancing teachers' digital proficiency and underscoring the necessity for institutional support (Akram et al., 2022). Collaboration methods, such as subject meetings and shared teaching responsibilities, further enhance professional development and support, enabling teachers to assist learners more effectively in utilising technological resources (Francom et al., 2021). These findings collectively demonstrate

that, as depicted in figure 1, teachers utilise a blend of self-directed learning, peer collaboration, and external assistance to adapt and integrate technology in education.

Collectively, the findings suggest that technology integration in Grade 11 Physical Sciences classrooms is shaped by the interaction of resource availability, infrastructure conditions and professional development opportunities. These factors influence teachers' capacity to create learning environments that promote exploration, inquiry and conceptual understanding, which are central principles of Constructivist Learning Theory. The study, therefore, adds to existing research by showing how contextual conditions within schools can influence the extent to which technology-supported teaching and learning can be implemented in Physical Sciences classrooms.

7. Limitations

This study has several limitations. First, the sample consisted of six teachers from six public secondary schools in the Tshwane South District, which limits the transferability of the findings to other contexts. Second, the study relied on self-reported interview data, which may reflect participants' perceptions rather than actual classroom practices. Third, the interviews lasted between 15 and 30 minutes and may, therefore, not have captured the full complexity of teachers' experiences. Despite these limitations, the study provides valuable context-specific insights into technology integration in Grade 11 Physical Sciences classrooms.

8. Conclusions and Recommendations

This study found that integrating technology into Grade 11 Physical Sciences education is hindered by interconnected challenges, including unbalanced resource allocation, insufficient connectivity, inadequate infrastructure, and a lack of school support. These limitations notably affect underfunded schools and hinder the effective use of technology, despite teachers' readiness to implement it. Professional development became essential, as teachers primarily relied on self-directed learning, peer collaboration and minimal external assistance due to limited formal training. The findings further indicated that successful technological integration requires a comprehensive strategy encompassing infrastructure, equitable resource distribution and ongoing professional development. Addressing these challenges requires equitable distribution, reliable infrastructure and sustained professional development for teachers. It is recommended that schools enhance collaborative teacher-support frameworks, while regulations must ensure reliable connectivity and focused, context-specific, and appropriate implementation. The study identifies a research gap in Grade 11 contexts and recommends further exploration of subject-specific approaches to technology integration. Enhancing technology integration requires aligning policy, practice, and teacher support to create equitable and meaningful learning outcomes.

9. Declarations

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Conflicts of Interest: The researcher declares no conflict of interest.

Data Availability: The data supporting the findings of this study are available from the corresponding author upon reasonable request. Access will be granted to researchers who meet the data-sharing criteria established by the institutional review board/ethics committee.

AI Usage: The researcher declares the use of AI-assisted tools in preparing this article. SciSpace was used to identify and screen literature sources, and Grammarly was used for spelling, punctuation, and grammatical editing. The researcher ensured that the intended concepts were preserved during the paraphrasing of the content and did not outsource their intellectual work to ChatGPT.

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