Towards Digital Classroom: Perspectives on the application and provision of information Communication Technology in teaching and learning

by

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DECLARATION

I, AFOLABI FAITH OLATUNDE, hereby declare that this dissertation is my very own work and that appropriate references have recognised all repositories cited.

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My gratitude extends to those committed to improving ICT infrastructure and training, recognising that these are crucial for transforming science teaching in Mpumalanga and beyond.

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ABSTRACT

The rapid evolution of Information and Communication Technologies (ICT) has transformed pedagogical practices globally; however, their effective integration into science teaching remains uneven, particularly in resource-constrained contexts. Guided by Activity Theory, this mixed-methods case study explores science teachers' perceptions and use of ICT-based instructional technologies to mediate and facilitate science learning activities in public secondary schools in Mpumalanga Province, South Africa. Data were collected from 83 in-service Physical Sciences teachers using a 38-item questionnaire comprising closed-ended Likert-scale items and open-ended questions. Quantitative data were analysed using descriptive and inferential statistics, including frequencies, means, standard deviations, and independent-samples t-tests. In contrast, qualitative data were analysed thematically using Braun and Clarke's (2006) six-phase framework.

Findings reveal that computers and smartboards are the primary mediating tools (44.58% usage each), while other technologies (e.g., online discussion platforms, mobile devices, projectors) remain underutilised. Teachers reported that ICT-based tools enhance science instruction by enabling flexible, anywhere-anytime teaching (97.6%), improving access to resources (97.6%), supporting diverse pedagogical strategies (87.3–89.2%), facilitating higher-order thinking (96.3%), and promoting active student participation and learner-centred roles (83–95.2%). Most items showed statistically significant agreement ($p < .001$). Qualitative findings corroborated these results, highlighting practical learning gains, improved interaction, timely feedback, and increased learner agency, although limited tool variety, infrastructural constraints, and varying teacher competence persisted.

The study aims to inform stakeholders about the current status of ICT integration, the challenges faced, and to provide recommendations to improve science education in Mpumalanga through ICT-based technologies.

Keywords: *Science teaching, ICT integration, instructional technologies, Activity Theory, teacher perceptions, Mpumalanga Province*

OPSOMMING

Die vinnige evolusie van Inligting- en Kommunikasietegnologieë (IKT) het pedagogiese praktyke wêreldwyd getransformeer; hul effektiewe integrasie in wetenskaponderrig bly egter ongelyk, veral in kontekste met beperkte hulpbronne. Gelei deur Aktiwiteitsteorie, ondersoek hierdie gevallestudie met gemengde metodes wetenskaponderwysers se persepsies en gebruik van IKT-gebaseerde onderrigtegnologieë om wetenskapleeraktiwiteite in openbare sekondêre skole in Mpumalanga Provinsie, Suid-Afrika, te bemiddel en te fasiliteer. Data is ingesamel van 83 Fisiese Wetenskappe-onderwysers in diens met behulp van 'n vraelys van 38 items wat geslote Likert-skaal items en oop vrae insluit. Kwantitatiewe data is geanaliseer met behulp van beskrywende en inferensiële statistieke, insluitend frekwensies, gemiddeldes, standaardafwykings en onafhanklike-steekproewe t-toetse. In teenstelling hiermee is kwalitatiewe data tematies geanaliseer met behulp van Braun en Clarke (2006) se sesfase-raamwerk.

Bevindinge toon dat rekenaars en slimborde die primêre bemiddelingsinstrumente is (44.58% gebruik elk), terwyl ander tegnologieë (bv. aanlyn besprekingsplatforms, mobiele toestelle, projektors) steeds onderbenut word. Onderwysers het berig dat IKT-gebaseerde gereedskap wetenskaponderrig verbeter deur buigsame, enige plek-en-tyd onderrig moontlik te maak (97.6%), toegang tot hulpbronne te verbeter (97.6%), diverse pedagogiese strategieë te ondersteun (87.3–89.2%), hoër-orde denke te fasiliteer (96.3%), en aktiewe studentedeelname en leerdergesentreerde rolle te bevorder (83–95.2%). Die meeste items het statisties beduidende ooreenstemming getoon ($p < .001$). Kwalitatiewe bevindinge het hierdie resultate bevestig en praktiese leerwinste, verbeterde interaksie, tydige terugvoer en verhoogde leerderagentskap uitgelig, hoewel beperkte gereedskapverskeidenheid, infrastruktuurbeperkings en wisselende onderwyserbevoegdheid voortgeduur het.

Die studie het ten doel om belanghebbendes in te lig oor die huidige status van IKT-integrasie, die uitdagings wat in die gesig gestaar word, en om aanbevelings te maak om wetenskaponderrig in Mpumalanga deur IKT-gebaseerde tegnologieë te verbeter.

Sleutelwoorde: Wetenskaponderrig, IKT-integrasie, onderrigtegnologieë, Aktiwiteitsteorie, onderwyserpersepsies, Mpumalanga Provinsie

ISIFINYEZO

Ukuthuthuka okusheshayo kwe-Information and Communication Technologies (ICT) kushintshe imikhuba yokufundisa emhlabeni jikelele; noma kunjalo, ukuhlanganiswa kwayo okuphumelelayo ekufundiseni isayensi akukalingani, ikakhulukazi ezimweni ezinqunyelwe izinsiza. Siqondiswa yi-Activity Theory, lolu cwaningo lwezindlela ezixubile luhlola imibono yothisha besayensi kanye nokusetshenziswa kobuchwepheshe bokufundisa obusekelwe ku-ICT ukuze kuxazululwe futhi kuthuthukiswe imisebenzi yokufunda isayensi ezikoleni zamabanga aphezulu zomphakathi eSifundazweni saseMpumalanga, eNingizimu Afrika. Idatha yaqoqwa kothisha be-Physical Sciences abangu-83 abasemsebenzini kusetshenziswa uhlu lwemibuzo lwezinto ezingu-38 oluqukethe izinto ze-Likert-scale ezivaliwe kanye nemibuzo evulekile. Idatha yobuningi yahlaziywa kusetshenziswa izibalo ezichazayo neziqondile, kufaka phakathi amaza, izindlela, ukuphambuka okujwayelekile, kanye nokuhlolwa kwe-t kwamasampula azimele. Ngokuphambene nalokho, idatha yobuningi yahlaziywa ngokwezihloko kusetshenziswa uhlaka lukaBraun noClarke (2006) lwezigaba eziyisithupha.

Okutholakele kwembula ukuthi amakhompyutha nama-smartboard yiwona amathuluzi ayinhloko okuxazulula izinkinga (ukusetshenziswa okungu-44.58% ngakunye), kuyilapho obunye ubuchwepheshe (isib., amapulatifomu okuxoxisana aku-inthanethi, amadivayisi eselula, amaphrojektha) kusasetshenziswa kancane. Othisha babike ukuthi amathuluzi asekelwe ku-ICT athuthukisa imfundo yesayensi ngokuvumela ukufundisa okuguquguqukayo, noma kuphi-noma nini (97.6%), ukuthuthukisa ukufinyelela ezinsizeni (97.6%), ukusekela amasu ahlukahlukene okufundisa (87.3–89.2%), ukwenza kube lula ukucabanga okuphezulu (96.3%), nokukhuthaza ukubamba iqhaza kwabafundi okusebenzayo kanye nezindima ezigxile kubafundi (83–95.2%). Izinto eziningi zibonise ukuvumelana okubalulekile ngokwezibalo ($p < .001$). Okutholakele kwekhwalithi kuqinisekisile le miphumela, kugqamisa izinzuzo zokufunda ezingokoqobo, ukusebenzisana okuthuthukisiwe, impendulo ngesikhathi esifanele, kanye nokwanda kokuxhumana kwabafundi, yize ukuhlukahluka kwamathuluzi okulinganiselwe, izithiyo zengqalasizinda, kanye nekhono lothisha elihlukahlukene kuqhubeka.

Ucwaningo luhlose ukwazisa abathintekayo ngesimo samanje sokuhlanganiswa kwe-ICT, izinselele ezibhekene nazo, kanye nokunikeza izincomo zokuthuthukisa imfundo yesayensi eMpumalanga ngokusebenzisa ubuchwepheshe obusekelwe ku-ICT.

Amagama angukhiye: Ukufundisa isayensi, ukuhlanganiswa kwe-ICT, ubuchwepheshe bokufundisa, Ithiyori Yomsebenzi, imibono yothisha, Isifundazwe saseMpumalanga

CHAPTER 1

INTRODUCTION AND BACKGROUND TO THE STUDY

1.1. INTRODUCTION

The Information and Communication Technologies (ICT)-based instructional technologies utilisation in education is discussed broadly in light of technological advances (Ahuja, 2016). We now live in a society where our daily activities depend solely on ICT. Subconsciously, individuals tend to use ICT tools for at least 1 to 2 hours daily. Globally, educational institutions have increasingly adopted ICT tools not only as supplementary aids but as central instruments in pedagogy, curriculum delivery, learner engagement, and educational management (OECD, 2022; UNESCO, 2023). ICT tools are devices that initiate communication and expand our knowledge. As the world grows globally, so does ICT. Hence, ICT is evolving over time and simultaneously impacting human lives. As such, human beings rely on ICT tools to communicate, access information, and stay connected in an increasingly globalised community.

In some parts of the world, the term “ICT” is already defined, and information technology (IT) is used interchangeably, but the two terms differ slightly in different contexts. According to Hogarty et al. (2003), the Quality Education Data report of 2000 denotes that “IT” is often used to refer to business operations, whereas “ICT” is more commonly used in the education and government sectors, particularly in the United States. It is imperative to note these differences, as this study focuses specifically on ICT in education. Information and Communication Technology is used in education to bolster, build, and advance the delivery of teaching and learning (Maharaj-Sharma & Sharma, 2017). In secondary school Science Education, these tools hold significant importance. They make it easier to visualise abstract concepts, replicate complex experiments through simulations, conduct real-time assessments, and tap into global pools of scientific knowledge (Chukwuemeka et al., 2019; Kibirige & Kwofie, 2021). The notable increase in the social use of ICTs and their significant impact cannot go unnoticed in education (Diyal & Pandey, 2022).

From the researcher’s perspective, ICT is already becoming an essential tool for both teachers and learners in the classroom. Globally, research reveals that ICT can improve student learning and enhance teaching methods (Nsofor & Bello, 2015). Tools such as video cameras, projectors, photocopiers, scanners, and others appeal to students' senses. These technologies help teachers communicate and explain to students in unique ways that facilitate learning. The effectiveness of ICT in teaching and learning in high schools is germane to recent educational development and innovation in Africa. The use of ICT-based instructional technologies is also gaining acceptance in education due to technological advances (Ahuja, 2016).

The goal of ICT in education can only be achieved when teachers are digitally literate and have the know-how to incorporate ICT into their curriculum. Different schools use varied sets of ICT tools to create, enhance, distribute, and manage information (Ghavifekr & Rosdy, 2015). In some perspectives, ICT is essential to teaching and learning interactions, including replacing chalkboards with interactive digital whiteboards (Mbugua et al., 2016). To this end, Maharaj-Sharma and Sharma (2017) observed that with the rapid growth of technology, and especially following the shifts brought on by the COVID-19 pandemic, there has been a global push to support teachers in adopting ICT-based instructional methods in science classrooms. These efforts aim to promote more meaningful, technology-enhanced learning experiences for learners.

1.2. THE STUDY'S BACKGROUND

Given the initiation of technology and its impact on human lives worldwide (Ahuja, 2016; Diyal & Pandey, 2022; Maharaj-Sharma, 2017; Maharaj-Sharma, 2016), the integration of ICT into education introduced a new dimension to various aspects of education. It made teachers' lives easier by making teaching more comfortable, accessible, and reliable. In addition, it has made knowledge acquisition easier and faster for learners. Learners can rely on e-learning technologies to access high-quality educational services anytime, anywhere, as required (Iqbal, 2024).

The White Paper on e-Education of 2004 recognised the need to integrate Information and Communication Technologies (ICTs) into teaching and learning (Department of Education [DoE], 2004). This implies that all South African schools have the obligation of integrating ICT as a central component of instructional practice. Thus, the incorporation of technology into teaching and learning is recognised as a means of transforming science instruction in secondary school education. The context of this study comprised public secondary schools located in Mpumalanga Province, South Africa.

Significant transformations in curriculum reform, management, governance, and teacher professional development have occurred in South Africa's education system since 1994. According to Gibson, Broadley, Downie, and Wallet, (2018). These reforms have been accompanied by deliberate efforts to integrate information and communication technology (ICT) into education, which are supported by national policies that advance long-term educational goals. The South African ICT policy, The White Paper on e-Education (Department of Education [DoE], 2003:18), states that e-learning initiatives can expand access to educational opportunities, address historical inequalities, enhance the quality of teaching and learning, and promote lifelong learning. Like many other developing states, South Africa adopted formal ICT policies to expand access to digital tools and meaningfully integrate technology into education. One such initiative is the country's national broadband policy 'South Africa Connect' introduced in 2013, which aims to ensure that every primary and secondary school has broadband access with download speeds of at least 100 Mbps by 2030 (Department of Communications, 2013). This policy recognises the importance of internet access for teachers and school leaders in supporting classroom learning and developing learners' digital competencies. Although various efforts have been made to equip teachers with ICT resources and skills (Botha et al., 2017; Maharaj-Sharma et al., 2017; Mbugua et al., 2016), the pace of integration into daily teaching practice remains slow across many schools in South Africa (Ramorola, 2018). Understanding how these national ICT policies are interpreted and implemented in the classroom level, especially by science teachers, is central to this research's purpose, which seeks to explore teachers' experiences and perceptions of ICT-based instructional technologies.

For this study, and in line with Ekici and Pekmezci (2015), the successful integration of ICTs into science teaching and learning could assist teachers in creating a technologically based virtual knowledge-sharing community of practice to successfully foster learning. Virtual learning could be more valuable and productive for teaching science subjects because it combines a variety of visual media, such as videos, graphics, MP3s, scanned images and animations, to effectively illustrate and instruct (Mbugua et al., 2016). Accordingly, these features can also help to illustrate scientific and highly abstract concepts that I find challenging to grasp. Broadly speaking, e-learning, including virtual learning, offers several advantages that make it a powerful supplement to traditional classroom teaching. Recent studies have shown that e-learning can eliminate geographical barriers by enabling learners to access quality education anytime, anywhere, and without resource constraints (Kaur, 2023). It can also support personalised learning by accommodating learners with diverse educational backgrounds, abilities, and learning preferences (Bashir & Lapshun, 2025; Lone et al., 2023). Furthermore, e-learning reduces mobility-related costs for learners, teachers, and other stakeholders seeking access to quality education (Lone et al., 2023). Collectively, these benefits highlight the potential of e-learning to promote equitable, flexible, and learner-centred educational experiences.

Taken together, the literature suggests that while South Africa has established a supportive policy framework and recognised the transformative potential of ICT in education, challenges remain in translating these initiatives into effective classroom practice, particularly in science teaching and learning.

1.3. STATEMENT OF THE PROBLEM

Despite the South African Department of Basic Education making heavy investments in ICTs such as projectors, whiteboards, smartboards, and other related technologies to foster teaching and learning, the way science is taught and learned in secondary schools has changed significantly. It is still unclear whether South African teachers are adequately prepared to incorporate ICTs into the science curriculum in secondary schools given the introduction of ICT-based instruction in the 21st century, when teaching and learning have been digitalised. It is unclear, though, whether South African science teachers are adequately prepared to use ICTs to enhance science curriculum instruction in secondary schools. Given the persistent challenges with science learner achievement, this concern is particularly important. Learners are expected to participate actively in digitally mediated learning environments by reading independently and constructing knowledge and solving problems at anytime and anywhere (Mnisi et al., 2024). Teachers require not only subject knowledge but also the pedagogical and technological competencies needed to support learner-centred approaches. Therefore, teachers who lack ICT competence may find it difficult to utilise digital resources effectively, which could potentially constrain learner engagement and academic performance in science subjects.

Previous studies have shown that many teachers lack the skills necessary to effectively integrate ICT into the teaching and learning of mathematics and science (Kaur, 2023; Maharaj-

Sharma et al., 2017). By contrast, teachers are generally more proficient in using basic computer applications, such as word processors and spreadsheet software, for administrative tasks, including preparing examination papers, processing results, and maintaining records (Ramorola, 2018).

Although most in-service teachers might be more familiar with ICT in general, they might not be able to integrate newfound e-learning technologies. In many schools, teachers might be reluctant to incorporate ICT to innovate teaching and learning (Lawrence & Tar, 2018). This could be as a result of their inadequate ICT and competency to effectively deliver classroom instruction (Maharaj-Sharma et al., 2017). This study, therefore, sought to explore how science teachers in Mpumalanga Province perceived and implemented ICT-based instructional technologies to improve learner performance. It aimed to uncover both the enabling conditions and the barriers that influence teachers' ability to translate national ICT policies into practical classroom strategies. In doing so, the study filled a gap in the literature about how South African rural science teachers engage with ICT and how contextual factors shape the uptake and impact of these technologies in real teaching environments.

1.3.1. The Study's Research Question

The main question for this research is, "*How do teachers perceive the integration of ICT-based instructional technology in the activities of the science subject in the Mpumalanga Province of South Africa?*"

Given the main study question, the subsequent research inquiries assisted in addressing the study problem:

1. What types of ICT-based instructional technologies are used by teachers to mediate activities in teaching science, and how can these inform future policy and training programmes?
2. To what extent are ICT-based instructional technologies integrated into science teaching practices?
3. What contextual, institutional, and policy-related factors influence the integration of ICT-based instructional technologies in science classrooms?
4. How do teachers and learners interact with ICT tools within the science teaching activity system?

To ensure coherence between the theoretical framework and the research design, it is important to demonstrate how each research sub-question aligns with the components of Activity Theory. While the questions may appear to emphasize teachers and ICT tools, they were intentionally structured to capture the broader dynamics of the activity system, including rules, community, and division of labour. The table below illustrates this alignment, showing how each sub-question corresponds to specific elements of the Activity Theory framework (Table 1.1).

Table 1.1: Alignment of Research Sub-Questions with Activity Theory Components

Research Sub-Question (SQ)	**Activity Theory Component(s) Addressed**	**Explanation**
SQ1: What are the objects or tools used by teachers to mediate the activities in the teaching of science?	Mediating Artefacts (ICT tools)	Focuses on the technological tools (computers, smartboards, projectors, etc.) that act as mediating artefacts in science teaching.
SQ2: To what degree does the use of ICT-based instructional technologies improve science activities?	Subject (Teachers) + Object (Science teaching activities)	Examines how teachers (subjects) use ICT to transform the object of activity (science teaching/learning tasks).
SQ3: What institutional and contextual rules influence how science teachers integrate ICT-based instructional technologies in their teaching activities?	Rules + Community	Captures the influence of school policies, institutional norms, and broader educational community expectations on ICT integration.
SQ4: What roles do teachers and learners play in the use of ICT-based instructional technologies during science teaching activities?	Division of Labour + Community	Explores how responsibilities are distributed between teachers and learners, and how community dynamics shape ICT-mediated teaching.

1.4. THE STUDY’S AIM AND OBJECTIVES

The primary aim of this investigation was to evaluate the integration of ICT-based instructional technologies into science subjects in the Mpumalanga Province of South Africa.

Given the study's aim, the following objectives were formulated to address the research questions.

1. To investigate the types of ICT-based instructional technologies used by teachers to mediate activities in science teaching.

2. To analyse the extent to which ICT-based instructional technologies have been used to improve science activities.
3. To examine the contextual and institutional factors influencing ICT integration in science classrooms.
4. To analyse how ICT tools mediate interactions between teachers and learners in science teaching activities.

1.5. THE STUDY'S SIGNIFICANCE

While research on ICT integration in teaching and learning has featured prominently in recent years, there are limited studies conducted on ICT-based technologies in teaching and learning the science curriculum in secondary schools. Numerous researchers have studied ICT integration in teaching and learning with a focus on teachers' technological competencies, access to and use of digital resources to support teaching and learning, as well as the barriers to and effective use of ICT to support teaching and learning (Botha et al., 2017; Chisango et al., 2020; Maharaj-Sharma & Sharma, 2017; Ramorola, 2018; Mnisi et al., 2024). There is lack of research in exploring ICT-based technologies in science instruction, especially in South Africa. Therefore, the current study was designed to fill the gaps in the area. The study could contribute to the body of knowledge on how teachers perceive and utilize various ICT-based resources to support teaching and learning in public secondary schools.

Moreover, it could contribute to the theoretical understanding of the range of social, institutional, and other contexts that influence the effective use of ICT in teaching and learning. Lastly, it should benefit policymakers, educational authorities, school managers, and teacher developers by providing a solid foundation for developing school-based strategies and interventions to improve the provision and effective use of ICT for teaching and learning in quality digital classrooms within South Africa.

1.6. THE STUDY'S DELIMITATIONS

This study is limited to in-service Physical Sciences teachers in public secondary schools in Mpumalanga Province, South Africa. The study examines explicitly teachers' perceptions and utilisation of ICT-based instructional technologies to enhance Science Education. The research excludes learners, school administrators, and other subject teachers. Additionally, the study focuses on specific educational districts where teachers participated in professional development workshops during the data collection phase. Consequently, the results are limited to the sampled population and context.

1.7. PRELIMINARY LITERATURE REVIEW AND THEORETICAL FRAMEWORK

The integration of information and communication technologies (ICTs) into education has been widely recognised as a driver of pedagogical innovation, particularly in science instruction. Global research has demonstrated that digital tools support more interactive, inclusive, and effective teaching and learning environments, particularly in subjects that require conceptual visualisation and experimentation (UNESCO, 2023). In Science Education, technologies such as animations, simulations, and virtual laboratories enable learners to engage more deeply with abstract content, allowing them to visualise scientific phenomena that might otherwise remain theoretical or inaccessible (Chukwuemeka et al., 2019; Kibirige & Kwofie, 2021).

These tools also aligned well with constructivist and inquiry-based learning approaches, which encouraged learners to question, hypothesise, and explore knowledge through guided discovery (Jonassen, 2006). ICTs provide platforms for modelling experiments, real-time assessments, and access to a range of instructional content. Studies from other sub-Saharan African countries, such as Kenya and Ghana, have highlighted positive outcomes in learner motivation and conceptual understanding when ICTs are used effectively in science instruction (Boateng & Adu-Gyamfi, 2022; Kiptalam & Rodrigues, 2021).

In South Africa, several policy frameworks, including the White Paper on e-Education (DoE, 2004), the National Development Plan 2030, and the South Africa Connect broadband policy (DoC, 2013), emphasise the need to embed technology in teaching and learning. These policies were further supported by initiatives from the Department of Basic Education (DBE), such as the ICT-in-Education Audit (DBE, 2022), which aims to assess and guide implementation efforts. However, practical integration in schools, especially in rural areas like Mpumalanga, remains patchy and often superficial. Teachers continued to face obstacles, including inadequate infrastructure, inconsistent access to digital tools, and limited technical or pedagogical support (Ramorola, 2018; Makhanya & Naidoo, 2020).

The existing literature also highlights a focus on ICT use across broad curricular areas, but relatively few studies have examined its role in the Physical Sciences specifically (Hardman, 2019). A few studies have explored how teachers interpret ICT policies and translate them into classroom practice. This study sought to address this gap by focusing on the specific experiences of science teachers in rural contexts.

Using Activity Theory (Engeström, 2001) as a guiding framework, the researcher positioned ICT as a mediating artefact within the broader system of teacher activity, shaped by institutional rules, community expectations, and role dynamics. By drawing from both international and local literature, the study acknowledged that while teacher training, infrastructure, and policy were all critical, understanding teachers' lived realities, especially in under-resourced settings, is key to advancing the effective and sustainable integration of ICT in Science Education (Tondeur et al., 2017; Chigona et al., 2021). The insights from this review informed the research design and conceptual foundation of the study.

1.8. SYNOPSIS OF THE RESEARCH DESIGN AND METHODOLOGY

In this section, a framework of the context in which the investigation was conducted is provided. This encompasses the research methods, research paradigm, study population and sample, research design, data compendium strategies and data analysis. A complete depiction of this study's plan and techniques is explained in Chapter 3.

1.8.1. Research Paradigm

Bhattacherjee (2012:17) describes research worldview as the 'plan and lead of research model by our psychological models or casings (belief system) of allusions that we use to compose our thinking and perceptions'. The two prevalent research worldviews are quantitative and qualitative. According to Creswell (2003:9), quantitative methods "advance the relationship among variables and pose this in terms of questions or hypotheses". At the same time, qualitative researchers often use open-ended questions, providing an opportunity for participants to express their views. Thus, the research employed an amalgamation of qualitative and quantitative data.

Therefore, this study was located within the pragmatic paradigm. This paradigm allows the researcher to take a non-partisan or fair-minded stance throughout data collection and analysis and to ensure that individual inclinations or biases do not adulterate the research findings. As indicated by Creswell (2003:12), "a pragmatist research paradigm design configuration is helpful to catch the best of both quantitative and qualitative approaches". Creswell (2003:12) further explains the notion of pragmatism and states, "A pragmatist researcher is not committed to any one system of philosophy and reality. This applies to mixed methods research in that inquirers draw liberally from both quantitative and qualitative assumptions when they engage in their research."

1.8.2. Research Methods

Leedy and Ormrod (2005:12) portray research methodology as "the overall procedures employed by the researcher to fulfil the research objectives, which could influence the selection of research instruments used by the researcher for data-collection, manipulation, clarification and presentation." The researcher espoused a mixed-methods research approach (Creswell, 2003) to accomplish the objectives of this research and collect and analyse data. A mixed-methods inquiry offers several approaches to investigation, depending on the sequence of data-collection methods and the level of significance assigned to each strategy (Creswell 2003). As Creswell (2003) indicates, a mixed-methods design can combine the strengths of quantitative and qualitative methodologies. Considering the above, a simultaneous, nested, mixed-methods approach was utilised for this research. Meaning that both qualitative and quantitative data were collected simultaneously.

1.8.3. Research Design

A research design is the overall plan and structure that guides the collection, measurement, and analysis of data in a study (Creswell & Creswell, 2018). It outlines how the research question will be addressed using specific methods and procedures. In this study, a case study research design was utilised to allow for a detailed, contextual exploration of how ICT-based instructional technologies are integrated into science teaching. According to Yin (2018), a case study is an empirical method that investigates an existing issue within its real-life context, particularly when the boundaries between the phenomenon and context are not clearly defined. This approach is particularly suitable when exploring complex, practice-based phenomena in education. Case studies are valuable for capturing participants' perspectives and understanding the interplay among factors influencing teaching and learning processes (Merriam & Tisdell, 2016). Given the study's goal of exploring how science teachers perceive and use ICT tools in real classroom settings, a case study design was considered most appropriate.

1.8.4 Study Population and Sampling

Elfil and Negida (2017:7) define study population as “the complete set of individuals, groups, or elements that share a specific characteristic relevant to a research inquiry. This population represents the broader group from which the researcher intends to conclude”. The study's target population was science teachers in secondary schools in Mpumalanga province, South Africa. According to Etikan and Bala (2017: 215), sampling is “the systematic ways of choosing participants, like people, objects, and other non-human resources such as printed resources, electronic archives, and various media resources from which data are collected for the study.” A list-based simple random sampling method was utilised to choose participants from teacher development workshops coordinated by district subject advisers in the four education districts: Nkangala, Ehlanzeni, Gert Sibande, and Bohlabela. A total of 83 teachers participated in the study voluntarily. The sample represented a range of rural and peri-urban (locations where urban and rural characteristics coexist) school contexts and provided sufficient variation to support descriptive and comparative analysis (Elfil & Negida, 2017; Etikan & Bala, 2017)**.**

1.8.5 Data-Collection Procedures

Since the Department of Education in Mpumalanga province (Research section) introduced a clause requiring data collection solely after school hours, it was challenging, if not impossible, for the researcher to conduct face-to-face interviews. As such, the researcher settled for both online and offline data-collection approaches. As a result, the researcher arranged with the subject advisers to attend professional workshops in each district. The survey was made available in three formats: (1) an online link via SurveyMonkey, (2) a QR code for mobile devices, and (3) printed hard copies for teachers without internet access. Informed consent was acquired, and participants completed the surveys at their own pace during the workshops.

1.8.6 Data-Analysis

Microsoft Excel and SPSS were utilised to code and analyse the quantitative data from closed-ended questions. Descriptive statistics such as frequencies and percentages were used to summarise ICT usage patterns, and independent t-tests were conducted to explore differences across demographic groups (Graue, 2015). Braun and Clarke's (2006) six-phase framework were used to thematically analyse the qualitative data from open-ended responses. The analysis involved familiarisation with the data, coding, theme identification, and interpretation, leading to rich insights into teachers' attitudes, challenges, and contextual experiences with ICT integration.

1.9. ETHICAL CONSIDERATIONS

This study's ethical clearance was obtained from the University of South Africa College of Education Ethics Review Committee and the Mpumalanga Department of Education. Ethical procedures, including confidentiality, informed consent, secure data management, and voluntary participation, are discussed in detail in Chapter 3.

1.10. ELUCIDATION OF LEXES

This segment defines the lexicon used in this inquiry to ensure a shared understanding of terms that may have varied meanings across educational and technological contexts. In this description, each term is provided, then a descriptor is presented, as shown below:

Table 1.2: Definitions of Core Concepts in ICT-Based Science Teaching**Term**	**Description**
Information and Communication Technology	Hardware, software, networks, and media for the collection, storage, processing, transmission, and presentation of information (Diyal & Pandey, 2022:28).
Teaching	A purposeful activity undertaken to facilitate learning or support the development of knowledge (Goodyear, 2015: 30).
Learning	A process that changes the learner and focuses on higher-order cognitive skills, rather than solely on acquiring facts or information (Johnson & Gallagher, 2021: 343).

ICT tools	Digital resources are used to support interaction, communication and collaboration in teaching and learning environments (Kaur, 2023: 15).
ICT-Based Instructional Technologies	Educational technologies specially designed or adapted to deliver, support or enhance teaching and learning (Saber, 2021: 505)
Technology Integration	Technology integration refers to the use of technological resources such as multimedia, hardware and software, web environments and other computer-related facilities to support teaching and learning (Ramorola, 2018:4)
Physical Sciences	The branch of science concerned with the study of non-living systems, including physics and chemistry (Brush & Spencer, 2025:1).
Science Activities	Structured tasks or practices that help learners to understand better the environment they live in; develop analytical thinking, problem-solving and coping skills (Evans, 2019:2)
Survey Monkey computer software	A web programme and a facilitating webpage that empowers an individual to build a study for usage on the web (Waclawski, 2012:477).
e-Learning	A mode of learning that uses digital technologies to deliver educational content and support instruction (Kaur, 2023:22)

1.11. THE STUDY'S EXPOSITION

An explanation of the contents of each chapter is provided in this section.

Chapter One introduced the study's foundation. This was followed by the problem statement and the intentions and intents of the investigation. An outline of the research plan and techniques, the study's significance, and the ethical issues were briefly clarified. This was followed by a discussion of the limitations of the study and clarification of the terms utilised in this research. Finally, the study's exposition was presented.

Chapter Two contains a review of the related literature, sorted and organised around the main research question and sub-questions. The purpose of this review was to investigate how ICT-based instructional technologies facilitate science teaching. Finally, the theories underpinning the study were provided.

Chapter Three highlights the research methods utilised in the study. First, the research paradigm, which followed a pragmatist research design, was presented. This was followed by the research strategies used in this inquiry. It was explained that this investigation utilised a mixed-methods approach. A portrayal of the research configuration was presented. Also, the inquiry design was presented, with a focus on the research setting, population, sample, and data collection. The chapter addresses issues of validity and legitimacy of the research instruments. Finally, the ethical issues were presented.

Chapter Four presented the quantitative and qualitative outcomes of the investigation. The outcomes were presented for each instrument utilised. The study’s quantitative findings were presented first, followed by the qualitative ones.

Chapter Five depicted the findings, followed by the study’s conclusion and recommendations.

1.12. CHAPTER SUMMARY

This chapter established the study's foundational context by examining the global and local significance of integrating information and communication technologies (ICT) into Science Education. It began by outlining the background to the inquiry and highlighting the persistent niche between ICT policy and classroom implementation, particularly in under-resourced settings such as Mpumalanga Province. The problem statement, aim, objectives and research questions were clearly defined, and the study's significance was explained from both theoretical and practical perspectives.

A preliminary literature review was included to position the study within existing scholarship, followed by a concise overview of the research methodology. This overview described the pragmatist paradigm, the mixed-methods case study design, and the sampling, data-collection, and analysis strategies. Ethical considerations were discussed in detail, confirming that all institutional and participant protections were respected throughout the research process. In addition, the chapter acknowledged the study's limitations and delimitations, explaining the scope and boundaries of its findings. Finally, the chapter outlined the structure of the remaining chapters of the dissertation, providing a roadmap for the reader. Collectively, these elements laid a comprehensive foundation for the more detailed literature review and empirical analysis presented in subsequent chapters.

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

This chapter explores key dimensions of Information and Communication Technology (ICT) integration within Science Education, with a particular focus on South Africa. It begins with an overview of the national education system, followed by a review of ICT's historical development in South African Schools. Subsequent sections examine specific aspects of ICT implementation. Different sections explore the incorporation of ICT tools in science classrooms, teachers' perceptions and acceptance, and the main facilitators and obstacles to ICT integration. In contrast, others highlight how ICT can enhance the quality and effectiveness of science teaching when applied thoughtfully and purposefully. The chapter outlines the theoretical and conceptual frameworks that underpin the study, emphasising how these theories jointly elucidate the dynamics of ICT utilisation among science teachers in South Africa.

2.2 THE SOUTH AFRICAN EDUCATION SYSTEM

The education system is structured into three levels: elementary, secondary, and tertiary. The DBE monitors adult literacy programmes and all schools from Grades R through 12, while the DHET manages universities and other post-school education and training institutions. It also manages the Human Resource Development Strategy for South Africa (HRDSSA). The DBE is tasked with creating and maintaining an education system that provides lifelong learning and skills for all citizens, thereby enhancing the quality of life and supporting a democratic society (DBE, 2022).

The South African Education System is divided into General Education and Training (GET) and Further Education and Training (FET) (Department of Basic Education, 2011). GET includes Grades R to 9, while FET includes Grades 10 to 12, as outlined in the *Curriculum and Assessment Policy Statement* (Department of Basic Education, 2011). Education is compulsory from age seven (Grade 1) to age 15 (Grade 9) (DBE, 2022). Schooling ranges from Grade R (Reception) to Grade 12, culminating in the National Senior Certificate (Matric). However, disparities persist. For example, in 2022, only 80.1% of learners passed the Matric exam, and performance varied sharply across provinces and school types (DBE, 2022). The South African school landscape is characterised by a tripartite categorisation comprising public schools, governing body-funded schools, and private schools. This classification reflects the country's socio-economic and historical realities, particularly those shaped by its apartheid legacy. Understanding the differences among these school types is essential to contextualising disparities in access to ICT resources and instructional quality in Science Education.

Public schools form the majority of basic education institutions and are fully subsidised by the state through the DBE. While public schools aim to ensure fair access to education, the quality of infrastructure and teaching resources often varies drastically across provinces and urban–rural divides. Rural and township schools are mostly overcrowded, have inadequate sanitation, and insufficient learning materials, including limited or non-existent ICT tools (UNICEF, 2022). Conversely, better-resourced public schools, usually located in urban areas, mostly have access to basic ICT infrastructure, such as computer labs or smartboards. However, these are often underutilised due to a lack of skilled personnel or technical support (Mhlanga & Moloi, 2020).

Governing body-funded schools, previously referred to as Model C schools, emerged from formerly whites-only institutions during apartheid and operate under a semi-privatised funding model. While they still receive government subsidies, they supplement operational costs through school fees, fundraising, and other community contributions. This additional financial capacity allows for improved facilities, better-qualified teachers, and the integration of ICT into daily classroom instruction (Hart, 2024). Consequently, these schools often perform significantly better in national assessments and are more likely to offer ICT-enabled science learning environments.

Private schools operate independently of the public system, although many are registered with the DBE and must comply with minimum academic standards. They tend to offer smaller class sizes, more specialised teaching staff, advanced ICT resources, and often follow curricula aligned with international examination boards such as Cambridge International or the International Baccalaureate (Cambridge Assessment International Education (CAIE), 2022). While the private education sector serves only about 5–7% of South African learners, its influence on educational quality and innovation is substantial (ISASA, 2021).

The implications of this tripartite system are profound for ICT-based science instruction. The unequal distribution of resources, including digital infrastructure and teacher training, creates significant disparities in learners' exposure to ICT-enhanced science curricula. Schools in affluent urban areas are far more likely to incorporate digital tools into teaching and learning, while those in under-resourced communities struggle with the most basic infrastructure (Pelser & Swanepoel, 2022). Thus, the type of school attended is a strong predictor of both the quality of Science Education received and the likelihood of encountering ICT-based instructional technologies. In Mpumalanga Province, however, the translation of these national ICT policies into classroom practice has been uneven. Rural schools in particular face infrastructural challenges such as unreliable electricity and limited broadband access, which directly affect science teachers' ability to implement ICT-based instructional strategies (Ngoveni et al., 2025). This contextual reality frames the present study's focus on how teachers in Mpumalanga perceive and utilise ICT tools in their classrooms.

2.2.1 Policy Development for ICT in South African Education

Early and effective digital adoption could be transformative for South Africa's economy. McKinsey & Company (2019) estimated that accelerated digitisation and automation could yield a net gain of up to 1.2 million jobs by 2030 and significantly lift productivity and per-capita income if public and private actors work together in bold and imaginative ways. However, achieving these outcomes depends critically on developing a digitally competent population, particularly future graduates equipped with technological fluency, critical-thinking skills, and adaptability to sectors shaped by artificial intelligence and automation.

Despite this potential, South Africa faces profound infrastructural and socio-economic barriers to widespread access to ICT. According to the General Household Survey (Stats SA, 2021), only 10.4% of households had internet access at home, and most access occurred via mobile devices rather than fixed connections. National data further show that approximately 27.3% of households owned a computer in 2021, with substantial disparities between urban and rural communities (Stats SA, 2022). These patterns align with broader research on South Africa's digital inequality, where affordability, geography, and income levels strongly shape technology use (Gillw et al., 2018; Sithole & Mbukanma, 2024).

Policy ambitions for digital integration in education go back two decades. The Department of Education's *White Paper on e-Education* (2004) envisaged that every learner and every teacher would be ICT-capable by 2013, integrating technology into learning, assessment, and school management. However, delivery has been uneven across provinces and phases. Case studies in both urban and township contexts document fragmented implementation capacity and the need for sustained teacher development alongside local support structures (Mkhize & Davids, 2021; Hart, 2023; Ramakgolo & Niyitunga, 2024).

The COVID-19 pandemic stress-tested the system. Schools and universities shifted to online platforms such as Zoom and Google Classroom, but outcomes varied considerably depending on institutional preparedness, connectivity, and device availability (Maringe & Chiramba, 2022). To mitigate access barriers, the government and regulators introduced zero-rating for selected educational websites. By January 2021, the Independent Communications Authority of South Africa (ICASA) reported that more than 1,000 health and education sites were zero-rated, and the Department of Higher Education and Training (DHET) published a complete list of approved educational URLs (ICASA, 2021; DHET, 2020). Still, affordability remained a significant constraint to equitable remote learning. The Alliance for Affordable Internet (A4AI) "1 for 2" benchmark defines affordable internet as 1 GB of mobile data costing no more than 2% of average monthly income, yet many African markets, including South Africa, have struggled to meet this target for low-income users (A4AI, 2022; ITU & A4AI, 2022).

Recent strategies signal a renewed commitment to digital equity. The *National Digital and Future Skills Strategy* (DCDT, 2020) and its 2021–2025 implementation programme emphasise building digital skills across the schooling and post-school sectors, encouraging public–private partnerships, and prioritising infrastructure investment (DCDT, 2022). Complementary analyses stress that infrastructure improvements must be paired with teacher training and school-level support to translate connectivity into meaningful pedagogy (Hart, 2024; Pelser & Swanepoel, 2022). While South Africa has long recognised the transformative potential of ICT in education, progress has been hampered by infrastructure deficits, affordability constraints, and uneven policy implementation. Realising the goals of national strategies requires a coordinated approach that aligns connectivity initiatives with sustained investment in teacher development and context-relevant digital resources.

The literature clearly indicates that a lack of infrastructure, teacher readiness, and socio-economic differences are significant obstacles to integrating ICT. However, these studies show that just having access to technology does not guarantee that teaching will change. The continued use of traditional teaching methods, even in schools with digital tools, shows that the problem is not just technical but also pedagogical and systemic. In Mpumalanga Province, where apparent differences between rural and peri-urban areas persist, it is essential to examine not only whether ICT resources are available but also how teachers use, understand, and apply them in their classrooms. This gap substantiates the current study's emphasis on teachers' lived experiences and contextual limitations.

2.2.2 Challenges to ICT-based education in South Africa

Empirical evidence from both developed and developing contexts consistently shows that effective ICT integration enhances learner engagement, motivation, and academic performance in science subjects (Seegobin, 2024; Sithole & Mbukanma, 2024). However, in South Africa, the realisation of these benefits remains uneven and often constrained by structural inequalities, inadequate infrastructure, and varying levels of teacher readiness.

Recent studies of public schools reveal that while teachers acknowledge ICT's transformative potential, actual use is frequently minimal or misaligned with curricular goals. Common barriers include unreliable electricity supply, limited digital literacy among educators, and poor access to functional ICT tools (Dlamini, 2022; Pelser & Swanepoel, 2022).

Earlier insights into the purposeful integration of ICT within learner-centred pedagogies remain relevant today. Such approaches expand access to educational resources and support interactive, individualised instruction (Tigere & Netshitangani, 2022). However, more recent evidence highlights that many South African teachers still lack the confidence and training needed to implement ICT effectively. As a result, they often revert to traditional lecture-based methods despite having access to digital tools (Moodley, 2015). The absence of sustained school leadership in driving ICT innovation, combined with a lack of context-specific professional development, further limits adoption.

Socio-economic conditions continue to shape ICT use, especially in under-resourced rural schools. The digital divide extends beyond the simple presence or absence of devices to encompass inadequate funding models, low levels of parental involvement, and infrastructural deficits (Mhlongo et al., 2023). Importantly, having technology in classrooms does not automatically lead to transformative teaching. Pedagogical innovation requires ongoing support, peer collaboration, and reflective teaching practices (Seegobin, 2024).

Studies show that successful ICT implementation in low-resource environments depends heavily on teacher beliefs, school leadership, and ongoing technical support (Sithole & Mbukanma, 2024). Professional learning communities and locally relevant training programmes, particularly those grounded in peer mentoring, have been shown to boost teacher confidence and foster instructional creativity (Dlamini, 2022). A complex interplay of factors shapes the educational value of ICT tools. Infrastructure availability, teacher digital skills, administrative support, and policy coherence, such as alignment between national ICT policies, teacher development programmes, and classroom practice, are critical. Without this strategic alignment, the promise of digital transformation in science teaching will remain challenging to realise, raising concerns about effective policy implementation and sustainability. These challenges are especially pronounced in Mpumalanga, where many schools lack adequate ICT laboratories and technical support. Teachers often report difficulties in sustaining ICT use beyond administrative tasks (Mathonsi, 2023), which raises critical questions about their preparedness to integrate ICT into science teaching, a central concern of this study

2.3 ICT TOOLS FOR SCIENCE EDUCATION

ICT tools have become indispensable for enhancing science teaching and learning at all educational levels. Their ability to visualise abstract scientific concepts, simulate complex natural phenomena, and support inquiry-based learning makes them particularly valuable in science instruction (Bishaw et al., 2022; Agyemang-Adarkwah et al., 2024). They also foster active engagement, collaborative problem-solving, and experiential learning. Globally, ICT has shifted from being a complementary resource to a pedagogical imperative, a change accelerated by the disruptions of the COVID-19 pandemic (Antoninis et al., 2023; Maringe & Chiramba, 2022).

Spreadsheets, such as Microsoft Excel and Google Sheets, are widely used for teaching scientific data handling. They support tasks such as tabulation, plotting graphs, and basic statistical analysis. Spreadsheets help learners identify trends and even model processes with real or simulated datasets (Adewale, 2024). Data projectors, including Liquid Crystal Display (LCD) and Digital Light Processing models, are often ceiling-mounted and connected to laptops or multimedia systems. These projectors enable teachers to present dynamic content such as scientific animations, videos, diagrams, and simulations, which enhances learners' understanding of complex concepts. For example, real-time demonstrations or 3D molecular visualisations can turn abstract theories into concrete, visual knowledge (Ajayi et al., 2018).

Interactive whiteboards (IWBs), also known as smartboards, offer even more sophisticated functionality. Connected to projectors and computers, IWBs allow teachers and learners to manipulate digital content directly using a stylus, finger, or electronic pen. These boards facilitate annotation, simulation playback, and the saving of class notes, all of which support active learning and differentiated instruction (Chigona et al., 2022). Many IWBs also integrate with learning management systems and educational software, allowing seamless transitions between learning activities.

When innovative technologies are unavailable, standard whiteboards and large plasma screens remain effective instructional aids. While they may lack the interactivity of IWBs, they remain valuable for projecting visual aids, explaining key concepts, and encouraging group participation. When paired with affordable projection equipment, these tools offer cost-effective options well suited to schools with limited resources (Shahi, 2024).

In science classrooms, ICT tools support constructivist learning environments in which learners actively engage in the learning process rather than passively receive information. They enable the visualisation, simulation, and manipulation of scientific phenomena that may otherwise be difficult to observe directly, such as atomic structures, photosynthesis processes, or environmental dynamics (Serevina et al., 2018; Ogegbo & Ramnarain, 2024). These tools also promote inclusive education by supporting multiple learning styles, including visual, auditory, and kinaesthetic modalities.

Nevertheless, the effectiveness of ICT in Science Education depends significantly on teachers' ability to meaningfully integrate these tools into their pedagogy. Without sufficient training, support, and curriculum alignment, ICTs may be used superficially rather than as a transformative learning tool (Jita, 2016; Agyemang-Adarkwah et al., 2024). Therefore, ongoing professional development, investment in school infrastructure, and promotion of innovative teaching strategies are necessary to realise the maximum potential of ICT in science classrooms.

Although the literature shows that different ICT tools can be helpful in teaching, it is often assumed that simply having access to them means they will be used well. However, how well these tools work depends a lot on how teachers plan their lessons and how effectively they connect technology to the curriculum's goals. In many South African classrooms, especially those that lack resources, the problem might not be a lack of tools but rather how well they are integrated and how often they are used in meaningful ways. So, this study not only lists available ICT tools, it also examines how science uses them to support learners in real classroom activity systems.

2.4 THE INTEGRATION OF ICT-BASED INSTRUCTIONAL TECHNOLOGIES IN SCIENCE CLASSROOMS

Science education is uniquely positioned to benefit from incorporating ICT-based instructional technologies, given its emphasis on experimentation, abstract concepts, and process skills. Many scientific phenomena cannot be directly observed, making them difficult for learners to understand using conventional, text-based methods alone. ICT tools such as simulations, animations, data-analysis software, and virtual laboratories allow learners to visualise and interact with these concepts in ways that bolster deeper comprehension and retention (Polly et al., 2021; Zandri & Harisman, 2025).

Studies have shown that topics such as atomic structure, thermodynamics, and ecological interactions are more effectively taught when supported by multimedia tools that bridge the gap between application and theory (Ogegbo, 2024). Interactive simulations, virtual labs, and augmented reality models can foster collaboration, critical thinking, and inquiry-based learning, enabling learners to engage actively with scientific problems (Bandekar et al., 2025).

The COVID-19 pandemic fast-tracked global digital adoption, including in South Africa. During school closures, teachers turned to platforms such as Zoom, Google Classroom, and WhatsApp to sustain instruction. However, the outcomes varied considerably depending on teacher preparedness, ICT skills, and access to resources (Gegenfurtner & Kollar, 2024). Some teachers successfully adapted lessons to leverage interactive features, while others reverted to static materials due to limited training or infrastructure.

ICT also supports differentiated learning by catering to diverse learning styles. Visual learners benefit from animations and videos, auditory learners from recorded lectures, and kinaesthetic learners from interactive modelling tools. Platforms such as PhET Interactive Simulations, Labster, and Arduino-based kits offer cost-effective, scalable laboratory experiences, which are particularly valuable in resource-constrained schools (Ghavifekr & Rosdy, 2015). Nevertheless, successful integration requires careful pedagogical planning. Poorly implemented ICT risks becoming a superficial add-on rather than an integral learning tool.

Effective use depends on aligning digital tools with curricular objectives, providing teacher training, and ensuring reliable infrastructure. Deliberate planning and professional support are essential to fulfil the full potential of ICT in Science Education.

This review has identified that ICT integration is most effective when embedded within pedagogical strategies rather than used as a supplementary add-on. However, much of the current research focuses on ideal or well-resourced environments, offering limited insight into how teachers in rural South African provinces navigate structural and contextual constraints. There remains a need to understand how science teachers interpret policy expectations and translate them into practical classroom action. By situating ICT use within Activity Theory, this study seeks to move beyond surface-level adoption and examine how tools, rules, community, and the division of labour collectively shape integration practices. In the Mpumalanga context, integration is further complicated by disparities between urban and rural schools. While some urban schools have begun experimenting with smartboards and projectors, rural schools remain dependent on basic computer applications (Ngoveni et al., 2025). This study, therefore, enumerates how contextual differences shape teachers' perceptions of ICT integration in science classrooms.

2.5 SCIENCE TEACHER ACCEPTANCE OF ICT-BASED INSTRUCTIONAL TECHNOLOGIES

The adoption of ICT in science classrooms depends heavily on teacher acceptance. Teachers' beliefs, attitudes, skills, and prior experiences shape how they use technology to support learning (Teo et al., 2018; Tondeur et al., 2017). Acceptance is not simply about mastering technical skills but also about recognising the value of ICT and integrating it meaningfully into practice (Alt, 2018). Confidence and institutional support also influence adoption. Teachers with prior positive ICT experiences tend to integrate technology consistently, whereas those facing technical barriers or lacking training often revert to traditional methods (Lawrence & Tar, 2018).

2.5.1 Factors Influencing Acceptance

A range of interlinked factors, including personal attitudes, institutional environments, and broader socio-cultural contexts, shape science teachers' decisions to adopt ICT-based instructional technologies. In Sub-Saharan Africa, and particularly in South Africa, these influences often intersect with structural challenges such as poor infrastructure and uneven possibilities for professional growth (Barakabitze & Lazaro, 2019). Recent research confirms that teacher attitudes towards ICT are among the most potent predictors of its adoption. In contexts where teachers perceive ICT as both beneficial and manageable, they are significantly more likely to integrate it into their lessons (de Wet & Rothmann, 2023). Prior successful experiences with technology, alignment with curricular goals, and confidence in technical skills often shape such attitudes.

Empirical evidence shows that professional development opportunities play a critical role in building these positive perceptions. Well-structured, contextually relevant training not only develops teachers' technical competence but also enhances their willingness to innovate pedagogically. Teachers who receive ongoing mentorship and participate in professional learning communities report more consistent and meaningful ICT integration (Hennessy, Hassler & Hofmann, 2015). Institutional culture and leadership also significantly influence adoption. Schools that prioritise technology in their strategic plans, encourage experimentation, and model digital innovation at leadership levels tend to have higher teacher uptake of ICT tools (Agyei, 2022). Conversely, environments lacking supportive leadership often see sporadic or superficial use of technology, regardless of available resources.

ICT adoption among science teachers is a multifaceted process that cannot be explained solely by access to devices. Attitudinal readiness, continuous skills development, supportive peer networks, and enabling institutional structures all interact to shape the likelihood of sustained and effective ICT incorporation in Science Education. For science teachers in Mpumalanga, acceptance of ICT tools is influenced not only by individual attitudes but also by contextual realities, such as resource availability and institutional support. This study specifically examines how these localised factors affect teachers' willingness and ability to adopt ICT in science teaching.

2.6 BENEFITS OF ICT IN SCIENCE EDUCATION

The integration of ICT-based instructional technologies has transformed science teaching and learning, offering pedagogical opportunities that go beyond those of traditional methods. These tools create dynamic, multimodal environments that align closely with the demands of scientific reasoning, inquiry, and problem-solving. By providing interactive, visual, and adaptive learning resources, ICT enables learners to explore complex ideas, conduct experiments in virtual environments, and collaborate in ways previously constrained by time, space, or resource availability (Polly et al., 2021).

One of the biggest advantages of ICT in Science Education is its capacity to enhance the visualisation of abstract concepts. Scientific phenomena such as molecular structures, astronomical events, or subatomic processes are often too small, too vast, or too rapid to be observed directly. Simulations, 3D models, augmented reality (AR) applications, and animations allow learners to see these processes in action. For example, PhET Interactive Simulations and Labster enable learners to manipulate variables, observe real-time outcomes, and build conceptual understanding through experiential engagement (Ghavifekr & Rosdy, 2015; Nipyrakis & Stavrou, 2022). This ability to see the unseen not only improves comprehension but also fosters curiosity and deeper questioning.

From a learner engagement perspective, ICT tools provide a more interactive and learner-centred learning environment. Unlike traditional teacher-led instruction, ICT-rich classrooms allow learners to take an active role in their own education. Platforms such as Google Classroom, Moodle, and Microsoft Teams provide spaces where learners can access resources, submit assignments, engage in discussions, and receive real-time feedback. Evidence suggests that these environments promote self-regulation, metacognition, and ownership of the learning process (Serevina et al., 2018; Savec, 2020).

ICT also supports collaborative and cooperative learning. Through online forums, shared documents, and virtual conferencing tools such as Zoom and Google Meet, learners can collaborate on science projects regardless of their physical location. This connectivity fosters peer-to-peer learning, collaborative problem-solving, and the exchange of diverse perspectives. International collaborations, such as cross-school or cross-country science investigations, become feasible through ICT, thereby broadening learners' exposure to different scientific approaches and cultural perspectives (Kundu & Bej, 2021).

From a teacher's perspective, ICT offers significant benefits in content delivery, assessment, and differentiation. Teachers can use interactive simulations to demonstrate phenomena that are dangerous, expensive, or impractical to replicate in physical laboratories. Formative assessment tools such as Kahoot, Quiz, and Google Forms provide instant feedback, allowing teachers to adapt instruction to learners' needs in real time. This adaptability supports differentiated instruction, ensuring that both advanced and struggling learners receive appropriately challenging tasks (Aderibigbe & Dube, 2022).

ICT plays a vital role in promoting inclusivity and equity in Science Education. Adaptive learning platforms can adapt content delivery to learners' abilities and needs. Assistive technologies such as screen readers, voice-to-text converters, and real-time translation tools make science learning more accessible for students with disabilities or those teaching in a second language (Oyeleye & Uche, 2020). These tools help to reduce systemic barriers and promote equitable participation.

Importantly, ICT can serve as a bridge in resource-constrained contexts, such as rural or underfunded schools. Virtual laboratories and mobile learning apps offer affordable alternatives to costly equipment and physical lab space. In South Africa, where infrastructure disparities persist, such solutions can narrow the disparity between schools with abundant resources and those with limited resources. Mobile learning, in particular, has shown promise in delivering science content in low-resource settings due to its portability, affordability, and growing penetration of smartphones among learners (Makokoe & Netshandama, 2021).

ICT also fosters the development of the 21st-century competencies, including digital literacy, data analysis, critical thinking, and problem-solving, that are increasingly essential in STEM careers. Learners who engage with ICT in science classrooms not only master subject-specific content but also gain transferable skills that prepare them for higher education and the workforce (UNESCO, 2021).

Furthermore, the flexibility of ICT enables lifelong learning by allowing learners to revisit recorded lessons, access multimedia resources, and engage in self-paced study beyond the classroom. This flexibility proved invaluable during the COVID-19 pandemic, when school closures necessitated remote instruction. While challenges in access persisted, many teachers reported that recorded science lessons, online simulations, and mobile learning tools helped sustain learner engagement and continuity of learning (Mhlanga & Moloi, 2020; Mtebe et al., 2021).

In summary, ICT enriches Science Education by:

i. Enhancing conceptual understanding through visualisation tools
ii. Promoting active, collaborative, and self-directed learning

iii. Enabling differentiated and inclusive instruction
iv. Bridging resource gaps in underfunded schools
v. Supporting the acquisition of transferable 21st-century skills
vi. Extending learning outside of the classroom and fostering lifelong engagement with science

However, these benefits are maximised only when ICT is meaningfully integrated into pedagogically sound lesson plans, aligned with curriculum outcomes, and supported by teacher professional development.

2.7 FACTORS HINDERING AND FACILITATING ICT INTEGRATION IN SCIENCE TEACHING

A dynamic interplay of barriers and enablers influences the integration of ICT-based instructional technologies into science classrooms. While the potential benefits of ICT improving teaching and learning are well documented, practical realities often limit its consistent and meaningful use. These realities are shaped by infrastructural, pedagogical, policy, and cultural factors.

2.7.1 Barriers to ICT Integration

One of the most persistent obstacles is infrastructure limitations. Many South African schools, especially in township and rural areas, lack reliable electricity, stable internet connectivity, and up-to-date digital devices. Even when ICT tools are available, they may be outdated or incompatible with modern software, reducing their pedagogical relevance. Such infrastructural constraints deepen existing inequalities between well-resourced and under-resourced schools, limiting opportunities for interactive science teaching (Momčilović & Ninković, 2024).

A second significant barrier is teacher preparedness. Effective ICT integration requires not only technical competence but also confidence in applying digital tools to support pedagogy. However, many science teachers have had limited exposure to ICT during pre-service training, and in-service professional development is often sporadic or generic. This lack of preparation can lead to low confidence, resistance to change, and reliance on teacher-centred methods.

Research shows that these internal barriers, beliefs, attitudes, and self-efficacy can be as significant as external constraints in shaping ICT use levels (Lekhu, 2023; Ghazali et al., 2024).

Policy gaps also hinder integration. In some schools, there is no clearly articulated ICT strategy or dedicated ICT coordinator to provide guidance, troubleshoot technical issues, and ensure alignment with curricular goals. Without coherent leadership and policy direction, ICT initiatives risk fragmentation and unsustainability. Moreover, when ICT use is not embedded in school development plans, it is often treated as an elective rather than a crucial component of teaching and learning (Tucker et al., 2024). In Mpumalanga, barriers such as inadequate infrastructure, limited professional development opportunities, and inconsistent access to digital devices remain persistent. These barriers directly inform the research questions of this study, which seek to understand how teachers navigate such constraints in their daily practice

2.7.2 Facilitators of ICT Integration

Despite persistent challenges, several factors can significantly accelerate the adoption of ICT in science classrooms. One of the most consistent enablers is sustained, subject-specific professional development. Ongoing, hands-on training tailored to Science Education equips teachers not only with technical know-how but also with the pedagogical strategies needed to integrate ICT into inquiry-based and conceptual learning. When this training is paired with mentorship, peer observation, and feedback loops, it fosters teacher confidence and encourages pedagogical innovation (Petko et al., 2023; Tondeur et al., 2021; Mpungose, 2022).

A supportive school culture is equally important. Schools that value collaboration, encourage experimentation with digital tools, and establish communities of practice create fertile ground for ICT adoption. In these environments, teachers share resources, co-create lesson plans, and jointly troubleshoot challenges leading to more consistent and impactful ICT use (Gudmundsdottir & Hatlevik, 2020; Trust et al., 2021).

Leadership commitment plays a decisive role. Principals and Department Heads who actively champion ICT adoption by allocating resources, aligning policies, and modelling technology use signal its importance and create a climate where innovation is rewarded. Leaders who set clear expectations, monitor progress, and recognise exemplary practice strengthen ICT's position as a transformative tool in Science Education (Avidov-Ungar & Forkosh-Baruch, 2021; Wang et al., 2023).

2.7.3 Instructional Roles of ICT in Science Education

ICT in Science Education fulfils multiple, interconnected instructional roles that, when applied strategically, can transform teaching and learning.

- ICT as Tutor: Digital platforms, such as AI-powered adaptive learning systems, deliver structured, personalised content that adapts to each learner’s pace and provides real-time feedback. These systems can address misconceptions early and support differentiated learning (Akram et al., 2023).
- ICT as Learning Environment: Virtual laboratories, interactive simulations, and augmented reality models immerse learners in rich, exploratory environments where they can manipulate variables, test hypotheses, and visualise abstract phenomena that might be inaccessible in a traditional lab setting (Polly et al., 2021).
- ICT as a Learning Tool: Applications such as spreadsheets, graphing software, and modelling programmes enable learners to collect, analyse, and represent scientific data, fostering authentic engagement with scientific practices (Mpungose, 2022).
- ICT as Research Tool: With access to online databases, open-access journals, and credible digital repositories, learners can develop information literacy skills by finding, evaluating, and synthesising scientific evidence (Muriithi & Makonye, 2022).
- ICT as Collaboration Tool: Platforms such as Google Workspace, Microsoft Teams, and virtual conferencing systems enable learners to work together on projects across classrooms, schools, and even countries, promoting global scientific collaboration and digital citizenship (Valdez et al., 2022).

When integrated thoughtfully, these roles work in synergy to create active, learner-centred science classrooms that prepare learners for participation in a digitally interconnected world.

2.8 THEORETICAL FRAMEWORK AND CONCEPTUAL FRAMEWORK

Given the complexity of ICT integration in science education, this study adopted an integrated theoretical approach. Activity Theory (AT) was used to capture systemic contradictions and interactions within the activity system (Engeström, 1987; Mwanza, 2002), while the Theory of Planned Behaviour (TPB) provided insights into individual teacher attitudes, intentions, and perceived behavioural control (Ajzen, 1991). The conceptual framework grounded these perspectives in the practical realities of ICT use in classrooms (Creswell, 2018). These frameworks ensured that both systemic and behavioural dimensions of ICT integration were addressed.

The integration of ICT in Science Education is a multifaceted process influenced by psychological, institutional, and socio-cultural elements (Tondeur et al., 2008). The integration of these models enables the study to investigate both teachers' intentions and study utilises three complementing frameworks, the Unified Theory of Acceptance and Use of Technology (UTAUT), Activity Theory (AT), and the Theory of Planned Behaviour (TPB), to offer a comprehensive explanation of teachers' ICT adoption behaviour attitudes, as well as the structural and contextual factors that affect the effective implementation of ICT-based scientific instruction in South Africa (Venkatesh et al., 2003; Kozma, 2005), specifically in the Mpumalanga Province. Applying these frameworks to the Mpumalanga context allows the study to analyse how institutional rules, community expectations, and teacher-learner roles interact with ICT use in science classrooms. This alignment ensures that the theoretical lens directly addresses the study's research questions.

2.8.1 Unified Theory of Acceptance and Use of Technology

The UTAUT model, formulated by Venkatesh et al. (2003), integrates prior theories of technology adoption into a cohesive framework. It asserts that four constructs, namely: social influence, performance expectancy, facilitating conditions, and effort expectancy, dictate persons' behavioural intentions and actual technology utilisation. The UTAUT model has been extensively validated in education to understand teachers' preparedness to utilise digital resources (Bempah, 2025; Jingyi & Pamintuan, 2025). In Science Education, performance expectancy refers to educators' beliefs that Information and Communication Technology (ICT) enhances students' understanding of complex scientific concepts through visualisations or simulations. Effort expectancy pertains to the apparent simplicity of utilising these instruments, whereas social influence concerns the extent of motivation or anticipations from peers, administrators, and policymakers. In this study, effort expectancy assisted in the interpretation of responses in terms of perceived ease of use, such as whether teachers found ICT tools intuitive or required extensive training (Garone et al., 2019). Social Influence analyses the role of peer expectations, school leadership, and policy directives in shaping teachers' willingness to adopt ICT (Kim & Lee, 2020). Ultimately, favourable conditions, such as infrastructure, technical assistance, and leadership, dictate the sustainability of adoption (de Wet & Rothmann, 2023). Findings were examined in relation to infrastructural and institutional support, including access to devices, broadband, and professional development opportunities (Garone et al., 2019). The UTAUT is an appropriate framework for this study because the evidence splits into perceived teaching benefits, ease and capability of use, and social and institutional supports that shape teachers' ICT adoption. Across education settings, the four UTAUT constructs performance expectancy, effort expectancy, social influence, and facilitating conditions are repeatedly used to explain teachers' intention to use technology and their actual use behavior (Dahri et al., 2023; Garone et al., 2019; Lee, B., & Lee, 2025).

Within Mpumalanga province, this hypothesis explains why educators in resource-abundant urban institutions are more inclined to utilise virtual laboratories, data analysis tools, or interactive whiteboards than their counterparts in under-resourced rural institutions. Although educators recognise the value of ICT, its incorporation is mainly contingent on supportive environments and continuous professional development. Consequently, UTAUT offers a behavioural framework for analysing instructors' intentions and their implementation in reality.

2.8.2 The Activity Theory (AT)

While UTAUT focuses on individual decision-making, Activity Theory (AT) highlights the socio-cultural contexts in which these decisions take place. Based on Engeström's (1987) model of human activity, the AT defines technology use as a tool-mediated interaction involving the subject (teacher), object (pedagogical goal), tools (ICT resources), community (school environment), rules (policies and norms), and division of labour (roles and responsibilities). The AT provides a diagnostic approach for finding structural contradictions that impede ICT adoption. National policy may advocate for e-learning; nevertheless, inadequate connectivity, insufficient equipment, and a lack of leadership commitment pose obstacles to effective classroom implementation (Baran et al., 2023; Ssempala, 2021). Likewise, when institutional regulations emphasise, examination results over exploratory learning, educators may oppose ICT integration despite acknowledging its advantages (Hart, 2024). This study elucidates how institutional frameworks, school culture, and accessible resources influence teachers' actions and motives. It facilitates a deeper understanding of how communal factors, rather than individual intent alone, influence ICT activities in scientific classrooms.

2.8.3 The Theory of Planned Behaviour (TPB)

The Theory of Planned Behaviour (TPB) (Ajzen, 1991) offers a psychological rationale for teachers' technology-related decisions. It posits that attitude towards conduct, personal standards, and perceived behavioural control all influence intention and ensuing behaviour. In ICT integration, teachers' attitudes represent their assessment of technology's educational usefulness; subjective norms indicate the social pressure or support they encounter; and perceived behavioural control signifies their confidence and capability to utilise ICT effectively.

Recent data highlights the ongoing significance of the TPB. Wong et al. (2022) discovered that teachers' utilisation of educational technology is significantly influenced by self-efficacy and perceived institutional support. In contrast, Tondeur et al. (2021) highlight that favourable attitude must be supplemented with concrete resources and administrative endorsement. In Science Education, this indicates that teachers who recognise the advantages of simulations, data-modelling software, and virtual laboratories may refrain from utilising them due to insufficient training, time, or resources (Lekhu, 2023). This research uses the TPB to connect individual psychology with systemic factors by elucidating the interplay of motivation, norms, and perceived control in shaping behaviour. It emphasises that mere willingness is inadequate; authentic adoption occurs only when both confidence and contextual support are present. The study deliberately combined these three frameworks to balance breadth and depth. AT offered a systems-based lens for examining contradictions among subjects, artefacts, rules, community, and the division of labour. TPB complemented this by focusing on the motivational and behavioural aspects of teachers' use of ICT, while the conceptual framework ensured contextual relevance by situating these perspectives within the realities of science classrooms in Mpumalanga. This integration allowed the study to capture both systemic and individual-level factors influencing ICT adoption.

2.8.4 Integration of the Frameworks

Each of UTAUT, AT, and TPB elucidates unique aspects of ICT adoption. When combined, they provide a comprehensive picture of teacher behaviour within authentic educational settings. The UTAUT model elucidates the factors influencing adoption, including perceived usefulness, ease of use, and social impact; the TPB delineates the reasons behind teachers' intentions or reluctance to utilise ICT, focusing on attitudes, norms, and perceived control; while the AT framework examines how contextual systems facilitate or impede these behaviours. Collectively, these frameworks enable the current study to explore both micro- and macro-level factors influencing ICT integration in science classrooms in Mpumalanga.

A teacher may have a firm intention to utilise simulations (TPB) and acknowledge the educational value of ICT (UTAUT), yet may be unable to apply them due to institutional restrictions, such as insufficient equipment or inflexible school regulations (AT). The integrated model recognises that teacher readiness, motivation, and institutional capability must be aligned for effective ICT-based instruction to take place.

A limitation of this integrated approach is that the Community aspects of AT were primarily interpreted through the lens of the Subject (teachers), as the data collection instruments were teacher-centred. While this focus was necessary to meet the study's aim of exploring teacher perceptions, future research should broaden the scope to include learners, administrators, and policymakers to provide a more holistic view of the activity system.

2.8.5 Conceptual Framework

This study's conceptual framework synthesises insights from the three theories to illustrate how teacher beliefs and attitudes (UTAUT and TPB) interact with systemic enablers and constraints (AT) to influence the level and quality of ICT integration in science teaching. It assumes that successful ICT use emerges from the interplay between individual readiness, institutional conditions, and broader socio-cultural context. This integrated framework provides the analytical basis for interpreting teachers' lived experiences in Mpumalanga Province, guiding both the data-collection instruments and the interpretation of findings in subsequent chapters.

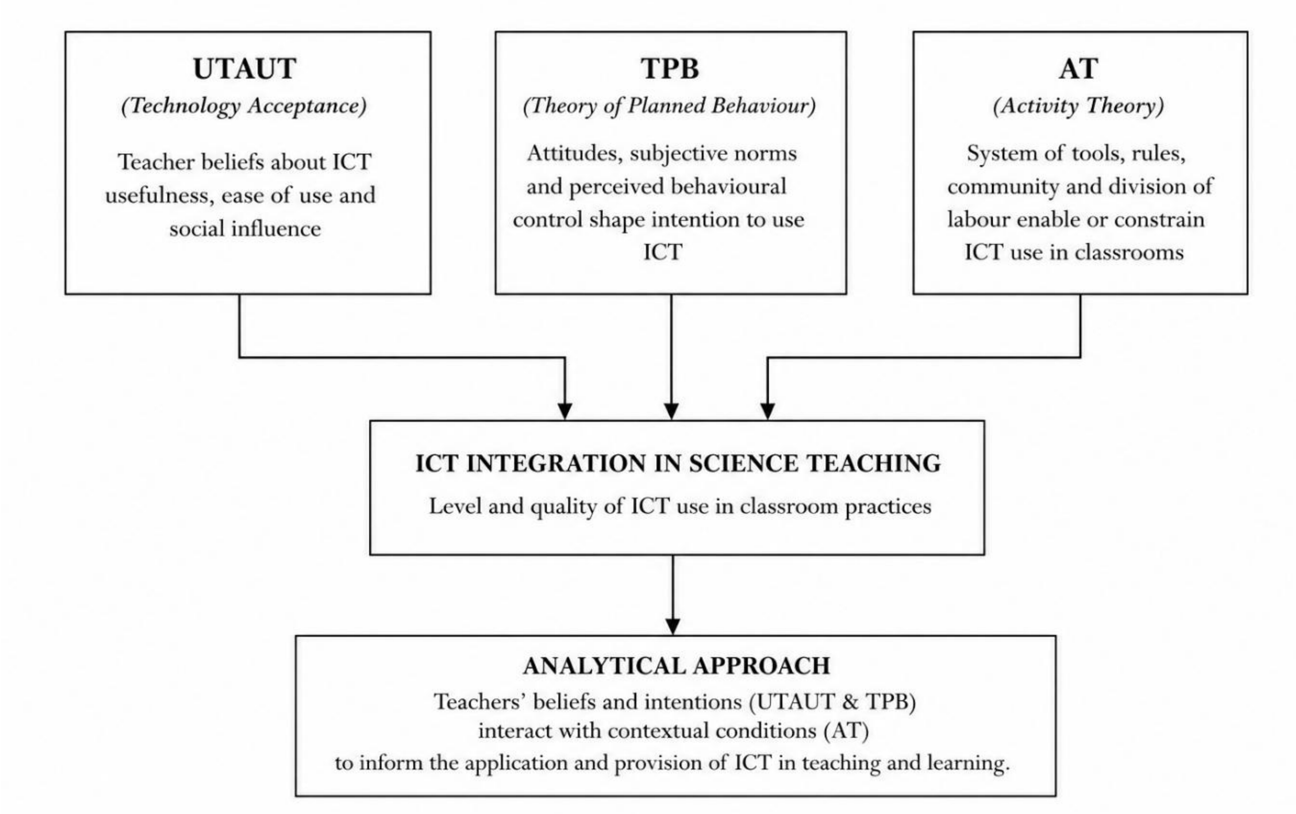

Figure 2.1: Integrated Conceptual Framework for Analysing ICT Integration in Science Teaching (designed by author)

2.9 CHAPTER SUMMARY

This chapter presents a comprehensive literature review of ICT-based instructional technologies in science education, with an emphasis on the South African Education System. It disclosed that, despite extensive regulations and technological progress, the incorporation of ICT is inconsistent across schools, mainly due to infrastructural deficiencies, limited teacher proficiency, and socio-economic disparities. This chapter's theoretical framework established the basis for comprehending these problems. The study integrated UTAUT, AT, and TPB to address both personal and systemic aspects of ICT adoption among science educators. This multifaceted method enabled the researcher to investigate both educators' goals and beliefs and the structural obstacles and enablers that influence their practice. This chapter delineated the conceptual and theoretical justification for the approach outlined in Chapter 3, which investigates science teachers' perceptions, adoption, and application of ICT-based instructional technology in Mpumalanga.

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

3.1 INTRODUCTION

This chapter outlines the inquest procedure and the blueprint used to ensure the study's effective conclusion. The chapter provides a research paradigm to locate the study. It also offers a comprehensive elucidation of the research setting, data collection techniques, and the methods used to analyse the collected data. In closing, the chapter portrays the researcher's role in the inquiry.

3.2 RESEARCH PARADIGM

Bhattacherjee (2012:17) describes the research worldview as the 'plan and lead of research model by our psychological models or casings (belief system) of allusions that we use to compose our thinking and perceptions'. The two popular research worldviews are quantitative and qualitative. According to Creswell (2003:9), quantitative methods "advance the relationship among variables and pose this in terms of questions or hypotheses". At the same time, qualitative researchers often use open-ended questions to allow participants to express their views. Thus, both qualitative and quantitative methodologies were used in the study. Creswell (2003) denotes that,

> A pragmatist research paradigm design configuration is helpful to catch the best of both quantitative and qualitative approaches. A pragmatist researcher is not committed to any one system of philosophy and reality. This applied to mixed-methods research, in which inquirers draw liberally from both quantitative and qualitative assumptions when conducting their study (p. 12).

For this reason, this study was conducted using the pragmatic paradigm, which permits the researcher to maintain objectivity or impartiality while gathering data and analysis processes and to ensure that personal preferences or prejudices do not pollute the research findings.

3.3 RESEARCH METHODOLOGY

Research methodology is the overall procedures the researcher utilised to achieve the aim of the investigation, which could affect the choice of research instruments used to collect data, and data manipulation, interpretation, and presentation (Leedy & Ormrod 2005:12). There are mainly three inquiry (Creswell 2003:18) strategies that someone can pick from when leading research. These are quantitative, qualitative, and mixed methods techniques. Creswell (2003) further describes the quantitative inquiry method as one in which the researcher essentially utilises post-positivist cases to develop expertise, employs procedures of inquiry such as research methods, and gathers information for predetermined applications that yield factual information.

According to the qualitative literature (Patton 2002; Strauss & Corbin 1990), qualitative inquiry is an approach that uncovers discoveries not achieved through arithmetic measures or other methods of quantification, wherein the intriguing phenomenon develops organically. On the other hand, a mixed-methods research approach is one in which researchers gather, analyse, and integrate both deductive and inductive data in a single inquiry or in a long-term programme of inquiry to address their research enquiries (Creswell 2003:6).

To achieve the objectives of this inquiry, the researcher adopted a mixed-methods approach to collect and analyse data.

3.3.1 A multiple methods approach

This study adopted a mixed-methods design, specifically a sequential explanatory model (Creswell & Plano Clark, 2018; Ivankova, Creswell & Stick, 2006). Quantitative data were collected first to provide a descriptive overview of ICT integration, followed by qualitative data to explain and enrich these findings. This design was chosen because it allows qualitative results to elaborate on quantitative outcomes, thereby strengthening the overall analysis. While the study relied on a single teacher-centred instrument, the integration of multiple theoretical frameworks guided interpretation rather than expanding data sources, ensuring coherence between the theoretical framework and the data presentation. Mixed-methods research enabled the researcher to use multiple methods. More specifically, blending methods from both the qualitative and quantitative approaches. A blended strategy of qualitative and quantitative methods allowed the researcher to investigate the research problem from various perspectives, thereby addressing it and providing appropriate recommendations. Importantly, the relevance of this approach is well established in existing research. Scholars argue that mixed methods designs are particularly effective for investigating complex social phenomena that involve both measurable patterns and subjective experiences (Fetters & Molina-Azorín, 2020).

Timans, Wouters, and Heilbron (2019) note that concurrent mixed-methods designs enhance the reliability of study results by integrating complementary data sources within a single analytical framework. Similarly, Creswell and Plano Clark (2018) emphasise that nested mixed methods designs are beneficial when one method requires reinforcement from another to explain or contextualise findings. The scholarly consensus supports the use of mixed-methods approaches in applied social research, health studies, and educational research, where they have been shown to yield richer, more actionable insights than single-method designs (Bazeley, 2018). By aligning with established scholarly practices, the mixed-methods approach adopted in this study enhances its methodological rigour, relevance, and contribution to existing knowledge.

3.4 THE RESEARCH DESIGN

The strategy that connects philosophical presumptions to particular techniques, such as survey, experimental, or ethnographic research, is known as a research design (Mbanaso et al., 2023)." To realise the intents of this study, the researcher used a case study design. According to Yin (1994: 13), a case study is an "empirical enquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident." This implies researching an object that is part of an open system and which both interacts with and is influenced by its environment (Graue, 2015: 31). Importantly, the case study design facilitated in-depth data collection and analysis by allowing the researcher to focus closely on the selected texts as bounded units within their specific cultural, historical and social contexts. The design also supported the integration of primary textual evidence with secondary scholarly sources, thereby strengthening interpretation and contextual understanding. Overall, the case study approach ensured depth, coherence, and analytical rigour by enabling the researcher to examine the complexity of ICT integration in teaching and learning as it unfolded within specific literary and socio-cultural environments.

Since this case study's purpose was to gain an in-depth understanding, the researcher adopted a mixed-methods approach (Creswell, 2012:535), utilising surveys as the primary data-collection method. This implied that quantitative design was the leading research approach for this study, because it permits the researcher to oversimplify the study's findings (Creswell, 2012:542). In this case study, a closed-ended questionnaire was used for the quantitative method, and an open-ended questionnaire for the qualitative method. The aim of using a case study design was to merge the conflicting strengths and shortcomings of quantitative and qualitative approaches (Creswell, 2012:535). However, the researcher adopted this design to validate and expand quantitative results using qualitative data.

3.5 THE RESEARCH SETTING

The research setting is the context in which a study is conducted (Etikan & Bala, 2017:200). The study was conducted in Mpumalanga Province, South Africa. Mpumalanga is located in the north-eastern part of South Africa. It is bounded by Limpopo province to the north, the country of Mozambique and Eswatini to the east, the provinces of KwaZulu-Natal and Free State to the south, and Gauteng province to the west. Mpumalanga Province has four education districts (see section 1.8.7.5). The study included secondary school Physical Sciences teachers across four educational districts within the Mpumalanga province, as depicted in Figure 3.1.

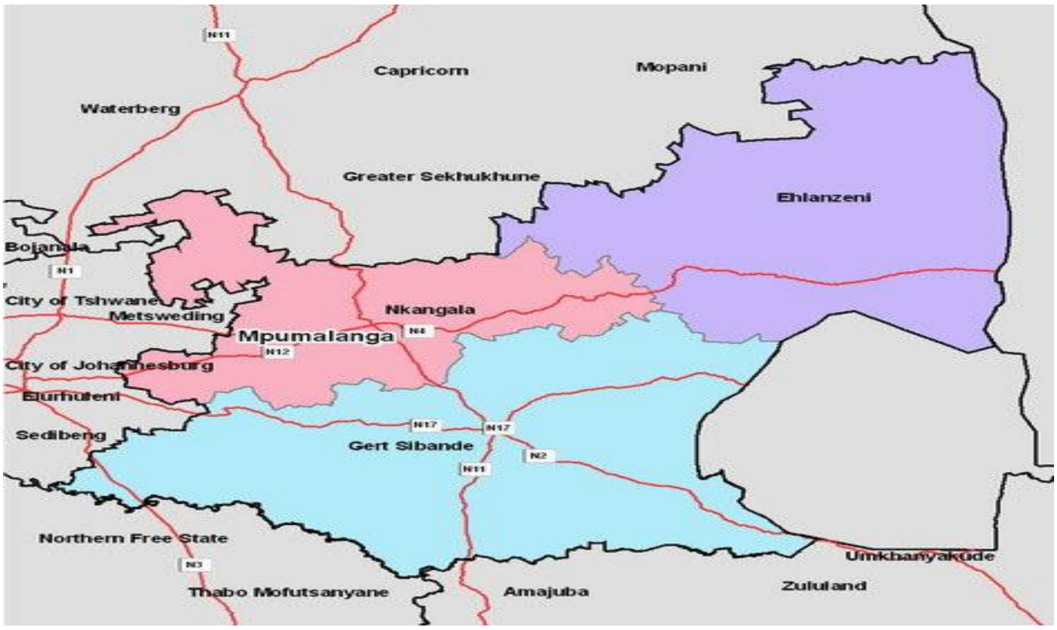

Figure 3.1. Four Educational Districts in Mpumalanga Province (Monkam, 2014)

3.6 POPULATION AND SAMPLING

A thorough description of the research population and the sampling strategy is given in this section.

3.6.1 Population

The target population for this study comprised all active Physical Sciences teachers in public secondary schools across the four education districts of Mpumalanga Province, namely, Nkangala, Ehlanzeni, Gert Sibande, and Bohlabela. According to district workshop attendance records obtained during the data-collection period, a total of 86 Physical Sciences teachers formed the accessible population for this study. From this accessible population, 83 teachers voluntarily participated in the study by completing the questionnaire. This represents a high response rate, indicating strong participation, and enhances the credibility of the findings. As per Efil and Negida (2017), a research population is "the summation of every item, subject, or person that sensibly speaking expectedly meet a lot of conditions and necessities." In the same tone, Castillo (2009:1) defines a research population as "a huge collection of people or items that become or are focused as the focal point of experiential research." The author further describes a research population as a well-characterised set of people or items considered to have similar attributes. Given the aforementioned, the study focused on science teachers in secondary schools in South Africa's Mpumalanga Province, which served as the study population.

3.6.2 Sampling

Sampling will be defined in this study as the systematic process of selecting a smaller, manageable group from a larger population to generate findings that meaningfully represent that population within the limits of the research design. In quantitative and mixed methods research, sampling is critical because it shapes the credibility and generalisability of the results, and the practical feasibility of data collection (Creswell, 2012). Probability sampling methods, such as systematic sampling, are commonly used to reduce selection bias and ensure that each person in the population has a known chance of getting included (Etikan & Bala, 2017; Elfil & Negida, 2017).

A systematic sampling method (Creswell, 2012:143) was used to select this study's participants. Members of a larger population are selected at regular intervals from a random starting point using systematic sampling, a probability sampling technique. Still, with a fixed, periodic interval (Elfil & Negida, 2017:9). The population size is divided by the intended sample size to determine this interval, also known as the sampling interval. For this study, simple random sampling was not favoured due to its inefficiency and time-consuming nature (Etikan & Bala, 2017: 215), whereas a systematic approach to selecting a sample size can be quick. Given this, a List-Based Sampling (LBS) frame was utilised for this study.

This sampling frame can be used just as one would for a traditional survey (Elfil & Negida, 2017:10). It generally begins with a summary of those who have access to the Internet. Given this, systematic sampling was used to select 83 Physical Sciences teachers in Mpumalanga province. The researcher was invited to meet with Physical Science teachers in the province during their in-house workshop on Physical Sciences. The number of participants is determined by the number of existing science teachers in the province for the academic year 2024, all of whom have completed at least a Diploma in Education Programme at a College of Education at any public University in South Africa. Everyone who took part was an active teacher teaching Physical Sciences in secondary schools in Mpumalanga Province of South Africa.

Furthermore, this study's inclusion and exclusion criteria were clearly defined to guarantee that participants were pertinent to the study's objectives and that the data collected were valid and reliable. The inclusion criteria comprised teachers currently employed as Physical Sciences teachers in public secondary schools in Mpumalanga Province, actively teaching during the 2024 academic year, and holding at least a Diploma in Education from a recognised public university or College of Education in South Africa. Participants were also registered attendees of the provincial in-house Physical Sciences workshop through which access to the population was facilitated, and they willingly provided informed consent to participate in the study.

The exclusion criteria applied to teachers who were not teaching Physical Sciences, those teaching at the primary school level or at tertiary institutions, teachers who were retired, on long-term leave, or not actively practising during the period of data collection, as well as individuals who did not meet the minimum professional qualification requirements. In addition, teachers employed in private schools or outside Mpumalanga Province were excluded to maintain contextual consistency and ensure that the sample accurately reflected the target population defined for this study (Creswell, 2012; Etikan & Bala, 2017).

3.7 DATA-COLLECTION PROCEDURE

As stated in Section 3.4, a multiple contextual investigation structure was used in this study. In this inquiry, an open-ended questionnaire was adapted from some earlier studies on ICT in education (Ghavifekr & Rosdy, 2015). Items from the adapted questionnaire were then modified to ensure they could be used in the context of science teaching in the Mpumalanga Province. Questions that sought information on access to and use of ICTs were adapted to accurately reflect the circumstances experienced in rural, as opposed to urban, schools. The structure of the adapted instruments was based on the validated instruments; modifications were made to ensure that they were suitable for the study. The questionnaire (see Appendix E) was developed for Physical Science teachers. Hence, the designed questions were clear. The researcher previously mentioned that the study was a mixed-methods study (see Section 3.3); thus, the questionnaire comprised two data sets: closed-ended and open-ended questions, which are covered in the following section.

3.7.1 Closed-ended questions

A five-point Likert scale with a rating range of 1 to 5 was utilised for the closed-ended questions that demonstrated the study's numerical component, which indicated the ‘strength of feeling or attitude’ (Bell, 1999:85). According to Bernard (2000:294), the rating scale is often referred to as a Likert-type scale. The Likert-type scale allowed the researcher in this study to use a more suitable questioning style rather than dichotomous (yes or no) style questions (Punch, 1998:95). Furthermore, as Miles and Huberman (1994:253) attest, the Likert-type scale enabled the researcher to include a ‘level of affectability and separation of rejoinder’ into the study.

The scale indicated: 1 = Strongly Agree (SA); 2 = Agree (A); 3 = Neutral (N); 4 = Disagree (D); and 5 = Strongly Disagree (SD). A neutral option was made available in case some participants were new to certain practices. The questionnaire contained 38 question items (QIs). Question Items 1–4 addressed respondents' demographic information. Question Items 6–30 were comprised of 26 questions, explained as follows:

- Question Item 5 sought information on objects or tools used by teachers to mediate activity in the teaching of science.
- Question Items 6–16 (11 questions) addressed whether ICT-based instructional technologies improved science activities.
- Question Items 17–23 (7 questions) addressed whether ICT-based instructional technologies regulated actions and interactions of activities in the teaching of science.
- Question Items 24–30 (6 questions) sought answers on the functions and tasks of participants in the activities of teaching science.

In each aspect, respondents rated their reactions on a five-point Likert-type scale.

3.7.2 Open-ended questions

The questionnaire featured a series of open-ended questions to guarantee that particular data were gathered. The goal was to compile comprehensive qualitative information from the science teachers on ICT-based instructional technology in science activities. The use of open-ended questions also helped collect potentially rich information that was relatively distinct from what the researcher anticipated (Tashakkori & Teddlie, 1998:102). In this regard, the questionnaire included eight questions (QIs 31–38) that asked for brief descriptions of how teachers used ICT-based instructional technologies to promote science activities in secondary schools.

To ensure clarity and consistency in data collection, the questionnaire was administered in person during a provincial in-house Physical Sciences workshop attended by teachers in Mpumalanga Province. Teachers were required to complete the questionnaire individually and were not allowed to take it home or complete it online. The questionnaire was completed at the workshop venue, where the teachers had gathered, rather than at their respective schools.

The questionnaire was administered after the workshop sessions concluded, to avoid disrupting the training and to ensure participants could respond without time pressure. Completing the questionnaire after the workshop also allowed teachers to reflect calmly on their teaching practices and experiences with ICT-based instructional technologies. Participants completed the questionnaire independently, and group discussion or collaboration during completion was not permitted to minimise response bias and guarantee the authenticity of the collected data.

Before the questionnaire was administered, clear instructions were given to the participating teachers on how to respond to the open-ended questions. The researcher explained that there were no correct or incorrect answers and that participants were expected to respond based on their personal teaching experiences and classroom practices. Teachers were instructed to provide brief yet clear descriptions of how they used ICT in science activities, with concrete examples where possible. They were also informed that their responses would be treated confidentially and used strictly for academic purposes. The questionnaire was given enough time to be completed, and participants were urged to respond to all open-ended questions on their own, without discussing them with colleagues, to ensure the reliability and credibility of the collected data (Tashakkori & Teddlie, 1998).

3.8 DATA-ANALYSIS

Data analysis summarised the collected data and involved interpreting data collected by applying logical and analytical reasoning to identify trends, correlations, or patterns (Tracy, 2024). Data analysis was one of the most essential parts of a qualitative study. Hatch (2023) clarifies that epistemological nature and underlying assumptions make qualitative data analysis a rich and often intricate process. In this study, data were collected using both quantitative and qualitative methods.

In this study, the unit of analysis was the constructs of Activity Theory (Engeström, 2001), namely mediating artefacts/tools, rules, community, division of labour, and outcomes. Both quantitative and qualitative data were examined in relation to these constructs to ensure consistency between the theoretical framework and the analytical process. The mixed-methods approach was applied sequentially, quantitative data analysis was conducted first to identify patterns of ICT use and perceptions, followed by qualitative analysis to provide deeper contextual insights. This sequencing allowed the Activity Theory constructs to serve as the interpretive lens across both strands of data, ensuring that findings were systematically connected to the study's theoretical foundation.

3.8.1 Quantitative Data Analysis

The quantitative data collected through the closed-ended questions were analysed using the Statistical Package for the Social Sciences (SPSS). The data were summarised using descriptive statistics, such as means and standard deviations. At the same time, an independent-samples t-test was conducted to determine whether ICT-based instructional technologies facilitate science teaching.

Data coding was a step in the analysis process, in which responses were converted to a numerical format for statistical analysis. In this regard, descriptive and inferential statistical techniques (Ong & Puteh, 2017:15) were employed to analyse the research questions. Descriptive analyses, including frequencies and percentages, were used to describe the data distribution (Pallant, 2015). Inferential statistics, including means, standard deviations, and independent-samples *t*-tests, were also performed to examine relationships and differences within the dataset (see Section 4.2).

In this study, a t-test was conducted to determine whether there were statistically significant differences between the datasets' mean values. A significance level of 0.05 was adopted for inferential statistical testing (Nahm, 2015:9).

3.8.2 Qualitative Data-Analysis

Qualitative data analysis in this study was defined as a systematic interpretive process through which open-ended textual responses were organised, coded, and examined to identify meanings, patterns, and themes that addressed the study's research questions (Creswell & Poth, 2018; Miles et al., 2014). Since the qualitative data were derived from teachers' written responses to open-ended questionnaire items, the analysis focused on identifying recurring ideas related to teachers' experiences, attitudes, challenges, and contextual realities of ICT integration.

To achieve this, data from the open-ended responses were analysed thematically using the six-phase framework proposed by Braun and Clarke (2006). Thematic analysis was considered appropriate because it is a flexible method for identifying and interpreting patterns of meaning across qualitative datasets, particularly where the aim is to summarise key experiences and challenges across a group of participants (Braun & Clarke, 2006; Nowell et al., 2017). The qualitative analysis followed Braun and Clarke's (2006) six-phase framework, as outlined below:

Phase 1: Familiarisation with the data

This phase involved reading and re-reading all open-ended responses to gain an overall understanding of the data. Preliminary notes were written to capture early observations, recurring issues, and notable statements, including challenges related to insufficient gadgets, poor internet connectivity, limited teacher training, and positive perceptions of ICT use. This immersion was essential for improving interpretive accuracy and avoiding superficial analysis (Braun & Clarke, 2006; Miles et al., 2014).

Phase 2: Generating initial codes

During this phase, meaningful units of text were systematically identified and assigned concise codes that captured the essence of each response. Examples of codes included "lack of ICT resources," "teacher training needs," "time constraints," "improved learner engagement," "curriculum pressure," and "network failure." Coding was applied consistently across the entire dataset, and responses containing multiple ideas were split and coded separately to preserve meaning (Braun & Clarke, 2006; Saldaña, 2021).

Phase 3: Searching for themes

After initial coding, related codes were categorised into broader categories and organised into potential themes. For example, codes such as "no computers," "few projectors," and "limited school devices" were combined into a theme labelled *Resource Constraints*. In contrast, codes such as "power outages" and "poor internet connectivity" formed the theme "Infrastructure Barriers." This phase enabled the identification of patterns across participants' responses (Braun & Clarke, 2006).

Phase 4: Reviewing themes

Themes were reviewed at two levels. First, each theme was examined in relation to its coded extracts to ensure internal coherence. Second, themes were compared to the complete dataset to confirm that they accurately represented participants' responses. Overlapping themes were merged, while overly broad themes were refined into clearer sub-themes to enhance analytical clarity (Braun & Clarke, 2006; Nowell et al., 2017).

Phase 5: Defining and naming themes

This phase involved refining and clearly defining each theme, specifying what it captured and how it related to the study objectives. The eight questions served as the themes in this regard.

Phase 6: Producing the report

The final phase involved presenting the themes in an articulate narrative, supported by direct quotations from teachers' responses as evidence (see Chapter 4). Interpretation was in line with the research questions and the relevant literature on ICT integration in education (see Chapter 5). Where appropriate, qualitative findings were integrated with quantitative results to deepen explanation and enhance interpretation (Creswell & Plano Clark, 2018).

Thematic analysis was suitable for this study because it provided a structured, credible approach to interpreting teachers' open-ended responses while allowing rich descriptions of real classroom experiences. Given that ICT integration is context-dependent and shaped by school resources, teacher competence, and systemic constraints, thematic analysis enabled these intricacies to emerge from the participants' narratives rather than being imposed through predetermined categories (Braun & Clarke, 2006; Nowell et al., 2017). The method also supported the study's mixed-methods design by allowing qualitative findings to explain and contextualise the trends observed in the quantitative data (Creswell & Plano Clark, 2018).

Throughout the investigation, a number of techniques were used to lessen bias and increase the reliability of the qualitative analysis. A detailed codebook was developed to ensure consistency in coding and interpretation across the dataset, thereby reducing subjective variation (Miles et al., 2014). Reflexive memoing was also employed, with the researcher documenting assumptions, analytical decisions, and reflections during the coding and theme development process to enhance transparency and reflexivity (Braun & Clarke, 2006).

In addition, a peer-review and audit-trail process was followed, during which coding decisions and emerging themes were examined for clarity, logic, and consistency in line with established qualitative quality standards (Nowell et al., 2017). Particular attention was paid to deviant or contradictory cases to ensure that minority perspectives were recognised and included rather than marginalised, thereby enriching the analysis (Creswell & Poth, 2018). Potential limitations, such as brief or unevenly detailed responses, were acknowledged, and interpretations remained firmly grounded in the teachers' data, avoiding unsupported assumptions or overgeneralisation.

3.9 RELIABILITY AND VALIDITY OF INSTRUMENTS

Reliability and validity were essential considerations in this study, particularly given the use of both quantitative and qualitative data. Tuval-Mashiach (2021) states that issues of validity and reliability are critical in quantitative research; however, they are treated differently in qualitative inquiry, as there is no intention to establish quantitative measures of validity and reliability. Reliability and validity both relate to the reasoning and precision of a research instrument. Similarly, Ghanad (2023) notes that reliability and validity determine whether a researcher measures what was intended and how dependable the research results are. This section explained how the researcher made sure the study tools were valid and reliable.

3.9.1 Reliability

The main goal of reliability measurement was to assess the internal consistency of each research instrument variable. A test was considered reliable when different researchers could use it under stable conditions, it produced consistent results, and the findings did not vary significantly over time.

Reliability referred to the production of similar results under consistent conditions. This understanding corroborates definitions provided by several researchers who describe reliability as the degree to which research findings remain consistent over time, accurately represent the population under investigation, and can be replicated using comparable methods (Creswell, 2012; Ahmed & Ishtiaq, 2021). However, reliability alone was not sufficient to guarantee validity. Therefore, it was the researcher’s responsibility to ensure a great degree of reliability and trustworthiness in both the research instruments and the results.

In this study, reliability was ensured by examining the consistency of responses obtained from the closed-ended questionnaire completed by Physical Sciences teachers from selected secondary schools. The responses demonstrated a reasonable level of consistency across items. Furthermore, the Cronbach’s Coefficient Alpha test (see Table 3.1) was used to assess the quantitative instrument's internal consistency, measuring ICT-based instructional technologies used in science teaching. While a minimum Cronbach's Alpha value of 0.70 is generally considered acceptable in educational and social science research, a cut-off value of 0.80 or above is widely regarded as evidence of good reliability (Taber, 2017:201). Table 3.1 presents the quantitative reliability results for the science teachers' responses.

Table 3.1: Science Teacher Quantitative Reliability Score

Items	**Number of Items**	**rα (Cronbach's Alpha)**
ICT tools or objects for teaching science	1	0.521
ICT-based instructional technologies improve science activities	11	0.834
ICT-based instructional technologies regulate actions and interactions of activities in the teaching of science	7	0.754
ICT-based instructional technologies on the functions and tasks of participants in the activity	7	0.965
Overall	26	0.769

Table 3.1 above shows the quantitative reliability scores for the science teachers. The Cronbach's Alpha value for all items was 0.769. According to Taber (2017), Cronbach's Alpha values between 0.45–0.98 are considered 'acceptable,' and values between 0.45–0.96 are considered 'sufficient.' Therefore, the closed-ended responses collected from the research participants were consistent.

3.9.2 Validity

Ahmed and Ishtiaq (2021:2402) describe validity in quantitative research as a means to establish whether the research instrument accurately measures what it was intended to measure and whether the study outcomes are dependable. This study's quantitative tool was specifically created and self-designed to address the research questions guiding the inquiry. Given this, careful attention was paid to establishing its validity.

First, content validity was ensured through an extensive review of relevant literature on ICT integration in Science Education, highlighting the instrument's rigour. The questionnaire items were derived from established constructs within the field, including technology usage, degree of integration, institutional rules, and participant roles. Each item was aligned explicitly with the research questions and the theoretical framework of Activity Theory. This alignment ensured that the instrument adequately covered the conceptual domains under investigation. The researcher and supervisor carefully reviewed the items for clarity and relevance to ensure alignment with the study's focus. Beyond this, two experts in the physical sciences and one ICT-in-Education specialist also reviewed and confirmed the proposals' alignment with the study’s objectives and theoretical framework. The questionnaire was logically structured, and the items were phrased appropriately for in-service teachers.

Second, construct validity was supported by structuring the questionnaire around key components of Activity Theory: mediating tools, rules, and the division of labour. By grounding the instrument in an established theoretical framework, the study ensured that the items measured theoretically meaningful constructs rather than isolated perceptions. The inclusion of both closed-ended and open-ended questions further strengthened construct validity by allowing triangulation between quantitative patterns and qualitative explanations. Five science teachers who were not part of the respondents in this study were pre-tested as part of the content validation process for initial checking for items such as: (a) Are all items clear? (b) Is correct usage employed? (c) Are all items correctly understood by respondents? Consistency was supported through the structured design of the Likert-scale items and the coherence observed in participant responses. The convergence between quantitative findings and qualitative data further strengthened the instrument's credibility.

Third, face validity was addressed through careful wording and item structuring to ensure clarity and relevance for in-service Physical Sciences teachers. The questionnaire was reviewed by the supervisor to confirm alignment with the study objectives and to eliminate ambiguous or leading statements.

Although construct validation techniques such as factor analysis were not performed, the reliability of the instrument was assessed using Cronbach’s alpha, which indicated acceptable internal consistency across the constructs (Table 3.1). Validity was further supported through methodological triangulation, thereby strengthening the robustness of the findings. Confidence was strengthened by the convergence of quantitative findings and qualitative responses indicating that the instrument captured consistent patterns of ICT integration in science classrooms.

Taken together, these measures enhanced the overall validity of the quantitative instrument and ensured it was appropriate for addressing the study's research objectives.

3.9.3 Trustworthiness

In qualitative research, trustworthiness refers to methods used to ensure that results are reliable, grounded in participants' real experiences rather than researcher bias. Qualitative research establishes rigour through methodological transparency and systematic verification, in contrast to quantitative research, which relies on statistical measures of validity and reliability. According to Lincoln and Guba (1985), trustworthiness is evaluated using four key criteria: credibility, transferability, dependability (or constancy), and confirmability. For this study, the researcher followed these criteria to ensure the trustworthiness of the findings. The instrument was pilot-tested to ascertain content validity.

3.9.3.1 Credibility (Internal Validity)

Credibility refers to the degree to which a study accurately reflects participants' experiences and ensures confidence in the findings (Gunawan, 2015:10). Ahmed (2024:1) notes that credibility ensures that the research theme is correctly understood and represented. To enhance credibility, the researcher employed several strategies.

Firstly, the researcher was an active Physical Sciences teacher in a government high school within the province, providing prolonged engagement and contextual familiarity with the study setting (Lemon & Hayes, 2020:605). Secondly, methodological triangulation was employed, using multiple data-collection methods to strengthen credibility (Carter, Bryant-Lukosius, DiCenso, Blythe, & Neville, 2014:545). Thirdly, member checks were conducted: participants reviewed the raw data and confirmed the accuracy of interpretations to enhance credibility (Lemon & Hayes, 2020:606).

3.9.3.2 Transferability

The degree to which results from a qualitative study can be transferred to different situations or groups with comparable traits is known as transferability (Lincoln & Guba, 1985). To facilitate this, detailed descriptions of the research context, participants, and procedures were provided, including information about participants' professional backgrounds, teaching environments, and the provincial setting. This level of detail enables readers to evaluate the applicability of the findings to their own learning contexts.

3.9.3.3 Dependability (Constancy)

Constancy, often known as dependability, refers to the research process's long-term stability and consistency (Lincoln & Guba, 1985). It ensures that research procedures are logical, traceable, and clearly documented. To ensure dependability, the research process was carefully planned and systematically followed, with clear documentation of the research design, sampling procedures, data collection methods, and data analysis steps. The use of a structured questionnaire and a clearly defined analytical framework ensured consistency in data collection and interpretation. Additionally, detailed records of methodological decisions and analytical procedures were maintained, creating an audit trail for verification by other researchers (Nowell et al., 2017).

3.9.3.4 Confirmability

The degree to which participant responses influence research conclusions rather than the researcher's bias, motive, or personal interests is known as confirmability (Lincoln & Guba, 1985). In this study, confirmability was enhanced by grounding interpretations strictly in participants' data and using verbatim excerpts to support emerging themes. Reflexive practices were applied, with the researcher maintaining awareness of personal assumptions and experiences that could influence interpretation. Peer review and audit trails further strengthened confirmability, ensuring that analytical decisions were transparent and logically derived from the data (Creswell & Poth, 2018). These measures ensured that the findings accurately reflected participants' experiences and perspectives instead of the researcher's personal opinions.

3.10 ETHICAL CONSIDERATIONS

Prior to their involvement, participants were properly informed about the nature, purpose, and scope of the study. In line with the principle of informed consent, they were provided with clear information regarding the research objectives, procedures, and their rights as participants (Israel & Hay, 2006). Participation was completely voluntary, and participants were informed that they could withdraw at any stage without penalty or negative consequences. It was also made clear that the study posed no foreseeable physical, psychological, or professional risk. Written or digital informed consent was acquired from every participant before data collection (see Appendix C). Participants were assured that their responses would be utilised exclusively for educational purposes and that no compensation would be provided.

Anonymity and confidentiality were central ethical principles guiding the study. Anonymity was ensured by not collecting any identifying information, such as participants' names or school names, and by guaranteeing that there was no way to connect individual responses to specific participants. Confidentiality was maintained by restricting access to the collected data to the researcher and supervisor, and by securely storing all electronic data in password-protected folders. The data are retained for five years post-study, after which all electronic and written records will be permanently destroyed to protect participants' privacy (Wiles, 2013).

3.11 RESEARCHER'S ROLE IN THE INQUIRY

The researcher played a central role in the design, execution, interpretation, and presentation of findings in this mixed-methods study. As an actively serving Physical Sciences teacher in a public secondary school in Mpumalanga Province, the researcher had practical knowledge of classroom realities, curriculum demands, resource constraints, and the everyday challenges of integrating ICT into science teaching. This insider status provided significant advantages, including contextual sensitivity, access to participants, and a sophisticated comprehension of the professional language and experiences shared by the teachers (Lemon & Hayes, 2020; Lincoln & Guba, 1985). However, the insider position also posed potential risks of bias and assumption-making. To address this, reflexivity was deliberately incorporated. The researcher engaged in continuous self-examination of personal beliefs, values, and assumptions, and carefully documented analytic decisions through memoing during data analysis (Braun & Clarke, 2006).

During data collection, a non-directive role was maintained to ensure participants were not influenced or pressured. The use of questionnaires allowed participants to respond independently and anonymously, reducing the likelihood of researcher influence (Israel & Hay, 2006). During analysis, coding, and theme development, the work was guided by established analytical frameworks, and interpretations were cross-checked through peer review and audit trails to enhance dependability and confirmability (Nowell et al., 2017). Divergent or contradictory responses were carefully considered to avoid privileging dominant narratives. Overall, the researcher's role was both interpretive and ethical. By acknowledging positionality, engaging in reflexive practice, and applying systematic analytical procedures, the study ensured that findings were grounded in participants' experiences rather than the researcher's preconceptions.

3.12 CHAPTER SUMMARY

The research design and methodology used in the study were presented in this chapter, demonstrating how the inquiry was structured to achieve its objectives and produce credible findings. The study was situated within a pragmatic research paradigm, supporting the use of both quantitative and qualitative approaches, and justified the selection of a concurrent nested mixed methods design (Creswell, 2003; Creswell & Plano Clark, 2018). This approach enabled the study to capture statistical trends through closed-ended questionnaire items while also gathering rich contextual insights from open-ended responses. The case study research design facilitated an in-depth investigation within a real-life educational setting, focusing on ICT-based instructional practices among Physical Sciences teachers in Mpumalanga Province.

The research setting, population, and sampling procedures were detailed to demonstrate systematic selection using probability sampling, including systematic and List-Based Sampling. Data-collection procedures were explained, including the questionnaire structure, Likert-scale items, and open-ended questions, to ensure accurate and independent responses. Data analysis procedures were outlined, including descriptive and inferential statistical analysis using SPSS for quantitative data and thematic analysis using Braun and Clarke's six-phase framework (2006) for qualitative responses. Reliability and validity measures were detailed, including Cronbach's alpha, expert review, and pilot testing. Trustworthiness in qualitative analysis was ensured through credibility, transferability, dependability, and confirmability strategies (Lincoln & Guba, 1985). Ethical considerations were rigorously followed.

Participants provided informed consent (see Appendix C), and anonymity and confidentiality were maintained. The researcher’s insider position contributed to contextual understanding while reflexive practices minimised bias.

In summary, this chapter laid a solid methodological framework for the investigation, ensuring that data collection and analysis were transparent, ethical, and appropriate for addressing the research questions. The next chapter presents and interprets the study's results using these procedures.

CHAPTER 4

PRESENTATION OF RESULTS

4.1. INTRODUCTION

This chapter presents quantitative and qualitative findings of this study in a structured yet integrated manner. While the results are organised according to the research questions for clarity, the findings should be viewed as interrelated components of a single activity system influencing ICT integration in science classrooms. The presentation, therefore, highlights both distinct patterns and the relationships among tool use, degree of integration, institutional rules, and participant roles in the classroom context. Before diving into the presentation of results, a recap of the study's main research question and sub-question is provided. The main research question was: How do teachers perceive the integration of ICT-based instructional technologies into science subject activities? The sub-questions were as follows:

1. What types of ICT-based instructional technologies are used by teachers to mediate activities in teaching science, and how can these inform future policy and training programmes?
2. To what extent are ICT-based instructional technologies integrated into science teaching practices?
3. What contextual, institutional, and policy-related factors influence the integration of ICT-based instructional technologies in science classrooms?
4. How do teachers and learners interact with ICT tools within the science teaching activity system?

4.2 QUANTITATIVE RESULTS

The quantitative results are presented in this section. The teachers responded to 26 question items (QI) on ICT tools or objects for teaching science (1 items); how they used ICT-based instructional technologies to improve science activities (11 items); how they used ICT-based instructional technologies to regulate actions and interactions of activities in the teaching of science (7 items); how they used ICT-based instructional technologies on the functions and tasks of participants in the activity (7 items).

4.2.1 Demographic information of the respondents

The respondents' demographic data are presented in this section, including gender, roles, and teaching experience.

Table 4.1: Gender of participants in the study

Gender		Frequency	Per Cent (%)	Valid Per cent (%)	Cumulative Per cent (%)
Valid	Male	62	74.7%	74.7%	74.7%
	Female	21	25.3%	25.3%	25.3%
	Total	83	100%	100%	100%

The data from Table 4.1 indicate that 62 (74.7%) male teachers and 21 (25.3%) female teachers participated in the study. This suggests that more male educators participated in the study.

Table 4.2: Current roles of participants in the study

Position		Frequency	Per Cent (%)	Valid Per cent (%)	Cumulative Per cent (%)
Valid	Teacher	64	77.1%	77.1%	77.1%
	Head of Department	17	20.5%	20.5%	20.5%
	Principal	2	2.4%	2.4%	2.4%
	Total	83	100%	100%	100%

Among the participants, the majority hold science teaching positions: 64 (77.1%) are teachers, 17 (20.5%) serve as Department heads, and a smaller fraction, 2 (2.4%), serve as Principals (Table 4.2).

Table 4.3: Teaching experience of participants in the study

Years of teaching experience		Frequency		Valid Per cent (%)	Cumulative Per cent (%)
Valid	Below 5 years	23	27.7%	27.7%	27.7%
	5-10 years	22	26.5%	26.5%	26.5%
	10 years and above	38	45.8%	45.8%	45.8%
	Total	83	100%	100%	100%

Regarding experience, 38 (45.8%) reported being in their roles for over 10 years, indicating a significant level of seasoned expertise within the group. Meanwhile, 23 (27.7%) reported having fewer than 5 years of experience, and 22 (26.5%) reported falling within the mid-range of 5 to 10 years (Table 4.3).

4.2.2 ICT tools or objects for teaching science

This section presents data on various ICT-based instructional technologies teachers use to enhance science activities. Figure 4.1 shows the objects or tools used by teachers to mediate activity in the teaching of science.

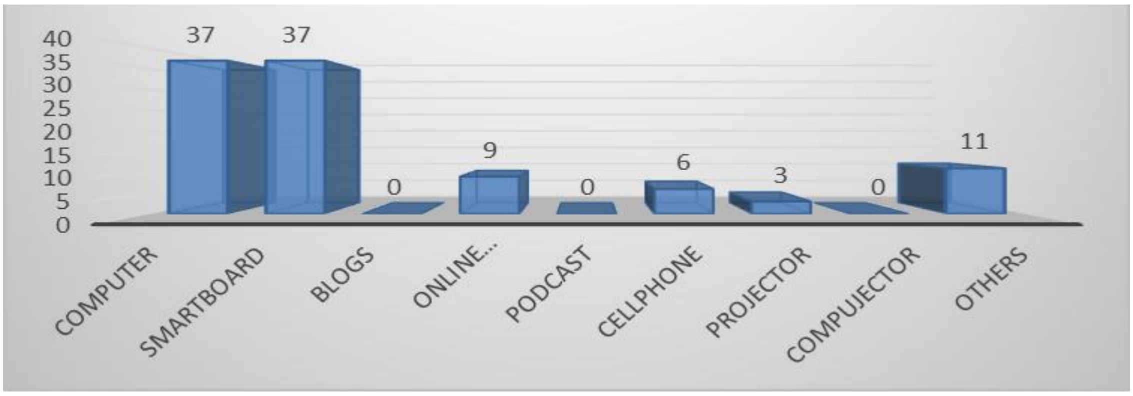

Figure 4.1: The objects or tools used by teachers to mediate activity in the teaching of science

The results revealed that computers and smartboards were the most frequently used tools, with 37 (44.58%) teachers using each in their instruction. Other resources, such as online discussion and cell phones, were used by fewer teachers: 9 (10.84%) and 6 (7.23%), respectively. This distribution highlights teachers' preference for digital and interactive tools, with computers and smartboards serving as primary resources for teaching science. In contrast, other tools were used only sparingly or not at all. It could mean that teachers need to adopt different ICT-based instructional technologies in the teaching of science to maximise the potential of technology (Figure 4.1).

Table 4.4: T-test on objects or tools used by teachers to mediate activity in the teaching of science

Instructional Technology	N	Mean (M)	Standard Deviation (SD)	Standard Error (SE)	t-value	p-value (2-tailed)
Computer	83	0.45	0.500	0.055	8.121	< .001
Smartboard	83	0.45	0.500	0.055	8.121	< .001
Online Discussion	83	0.11	0.313	0.034	3.158	.002
Cell Phone	83	0.07	0.261	0.029	2.528	.013
Projector	83	0.04	0.188	0.021	1.754	.083
Others	83	0.13	0.341	0.037	3.539	.001

Note: Values originally reported as .000 have been presented as $p < .001$, following APA and standard scientific reporting conventions. The result for Projector ($p = .083$) is not statistically significant at the 0.05 level, whereas the other instructional technologies show statistically significant results.

The results from Table 4.4 revealed the average level of agreement among teachers regarding the use of objects or tools to mediate activity in science teaching. Both computers and smartboards emerged as the most frequently used tools, with mean scores of 0.45 for each, a standard deviation of 0.500, and a standard error mean of 0.055. The high t-value of 8.121 for both tools, coupled with a significance level (p-value) of 0.000, indicated a statistically significant level of agreement on their use, reflecting a consensus on their importance in science teaching.

The results demonstrated a clear preference for computers and smartboards, which were the most widely used tools for mediating teaching activities in science classrooms. In contrast, other tools, such as online discussions, cell phones, projectors, and other resources, were less commonly employed, though each had some acknowledged use in supporting instructional activities.

4.2.3. The use of ICT-based instructional technologies to improve science activities

Table 4.5 presents data on the 11 QIs that required respondents to score how much they agreed with the degree of use and perceived effectiveness of ICT-based instructional technologies in enhancing science activities.

Table 4.5: The degree of use and perceived effectiveness of ICT-based instructional technologies in enhancing science activities (N=83)

Items	SA	A	N	D	SD
2. Using ICT-based instructional technologies allowed teachers to teach science anywhere and anytime.	58 (69.9%)	23 (27.7%)	2 (2.4%)	0 (0%)	0 (0%)
3. Using ICT-based instructional technologies for teaching science provides teachers with access to teaching materials/resources anytime, anywhere.	49 (59.0%)	32 (38.6%)	2 (2.4%)	0 (0%)	0 (0%)
4. The use of ICT-based instructional technologies for teaching science allows a teacher to teach in ways not formerly possible.	37 (44.6%)	28 (33.7%)	11 (13.3%)	6 (7.2%)	1 (1.2%)
5. The use of ICT-based instructional technologies permits the teacher to surf through e-books, e-libraries and journals.	42 (50.6%)	37 (44.6%)	4 (4.8%)	0 (0%)	0 (0%)
6. ICT-based instructional technologies tools used in teaching	41 (49.4%)	36 (43.4%)	4 (4.8%)	2 (2.4%)	0 (0%)

science mediate the activity in the teaching of science.					
7. ICT-based instructional technologies improve science teaching activities.	46 (55.4%)	32 (38.6%)	3 (3.6%)	2 (2.4%)	0 (0%)
8. The use of ICT-based instructional technologies supports the teacher in designing science activities that are responsive to their learners' needs.	38 (45.8%)	36 (43.4%)	7 (8.4%)	2 (2.4%)	0 (0%)
9. The use of ICT-based instructional technologies in science teaching supports the teacher in employing teaching strategies that are suitable for learners' needs.	30 (36.1%)	42 (50.6%)	11 (13.3%)	0 (0%)	0 (0%)
10. The use of ICT-based instructional technologies in science teaching supports the teacher to use evaluation strategies that suit learners' needs.	29 (34.9%)	44 (53.0%)	8 (9.6%)	2 (2.4%)	0 (0%)
11. The use of ICT-based instructional technologies in science teaching supports the teacher in formulating teaching objectives that are responsive to learners' needs.	22 (26.5%)	49 (59.0%)	9 (10.8%)	3 (3.6%)	0 (0%)
12. The use of ICT-based instructional technologies in science teaching enhances the delivery of science activities.	56 (67.5%)	24 (28.9%)	1 (1.2%)	2 (2.4%)	0 (0%)

QI 2 asked respondents whether the use of ICT-based instructional technologies allows teachers to teach science anywhere, anytime. In response, 58 (69.9%) respondents strongly agreed, and 23 (27.7%) agreed with the question. Apparently, 81 (97.6%) respondents strongly agreed and agreed that the use of ICT-based instructional technologies allows teachers to teach science anywhere and anytime.

QI 3 asked respondents whether the use of ICT-based instructional technologies for teaching science provided teachers with anytime, anywhere access to teaching materials/resources. To this end, 49 (59.0%) respondents strongly agree, while 32 (38.6%) agreed. Overall, 81 (97.6%) respondents strongly agreed and agreed that the use of ICT-based instructional technologies for teaching science provides teachers with access to teaching materials/resources anytime, anywhere.

QI 4 asked respondents to rate the extent to which the use of ICT-based instructional technologies for teaching science enabled the teacher to teach in ways not previously possible. In response to this question, 37 (44.6%) respondents strongly agreed, and 28 (33.7%) agreed. Thus, 65 (72.3%) respondents strongly agreed that the use of ICT-based instructional technologies for teaching science enabled teachers to teach in ways not previously possible.

QI 5 asked respondents whether the use of ICT-based instructional technologies enabled teachers to browse e-books, e-libraries, and journals. To this end, 42 (50.6%) respondents strongly agreed, and 37 (44.6%) agreed with the question. Overall, 80 (96.4%) respondents strongly agreed and agreed that the use of ICT-based instructional technologies enabled teachers to access e-books, e-libraries, and journals.

QI 6 asked respondents to rate how ICT-based instructional technology tools used in teaching science mediate the teaching activity. In this regard, 41 (49.4%) respondents strongly agreed, and 36 (43.4%) agreed with the question. Hence, 77 (92.8%) respondents strongly agreed and agreed that ICT-based instructional technology tools used in teaching science mediate the teaching of science.

QI 7 asked respondents whether the use of ICT-based instructional technologies improved science teaching activities. In response to this question, 46 (55.4%) respondents strongly agreed, and 32 (38.6%) agreed. Overall, 78 (94%) respondents strongly agreed that the use of ICT-based instructional technologies improves science teaching activities.

QI 8 asked respondents whether the use of ICT-based instructional technologies supports teachers in designing science activities that are responsive to learners' needs. To this end, 38 (45.8%) respondents strongly agreed, and 36 (43.4%) agreed with the question. Thus, 74 (89.2%) respondents strongly agreed or agreed that the use of ICT-based instructional technologies supported teachers in designing science activities responsive to their learners' needs.

QI 9 asked respondents to rate the extent to which the use of ICT-based instructional technologies in science teaching supports the teacher in employing teaching strategies suitable for students' needs. In response to this question, 30 (36.1%) respondents strongly agreed, and 42 (50.6%) agreed. Hence, 72 (87.3) respondents strongly agreed and agreed that the use of ICT-based instructional technologies in science teaching supports teachers in employing teaching strategies suitable for learners' needs.

QI 10 asked respondents whether the use of ICT-based instructional technologies in science teaching supports teachers in using evaluation strategies that suit student needs. To this end, 29 (34.9%) respondents strongly agreed, and 44 (53.0%) agreed with the question. Overall, 73 (87.9%) respondents strongly agreed that the use of ICT-based instructional technologies in science teaching supported teachers in using evaluation strategies that suit learners’ needs.

QI 11 asked respondents to rate whether the use of ICT-based instructional technologies in science teaching supports teachers in formulating teaching objectives that were responsive to learners' needs. Given that, 49(59.0%) respondents agreed, with 22(26.5%) strongly agreeing with the question. Thus, 72 (85.5%) respondents strongly agreed and agreed that the use of ICT-based instructional technologies in science teaching supports teachers in formulating teaching objectives that are responsive to learners' needs.

QI 12 asked respondents to rate the extent to which the use of ICT-based instructional technologies in science teaching enhances the delivery of science activities. To this, 56(67.5%) respondents strongly agreed, with 24(28.9%) agreeing to the question. To this end, 80 (96.4%)

strongly agreed or agreed that the use of ICT-based instructional technologies in science teaching enhances the delivery of science activities.

Table 4.6: T-test with respect to the degree of use and perceived effectiveness of ICT-based instructional technologies in enhancing science activities.

S/N	N	Mean (M)	Standard Deviation (SD)	Standard Error (SE)	t-value	p-value (2-tailed)
1	83	4.67	0.521	0.057	81.820	< .001
2	83	4.54	0.631	0.069	65.627	< .001
3	83	4.13	0.985	0.108	38.226	< .001
4	83	4.46	0.591	0.065	68.765	< .001
5	83	4.40	0.697	0.077	57.449	< .001
6	83	4.47	0.687	0.075	59.296	< .001
7	83	4.33	0.734	0.081	53.662	< .001
8	83	4.23	0.669	0.073	57.628	< .001
9	83	4.20	0.712	0.078	53.836	< .001
10	83	4.08	0.719	0.079	51.741	< .001
11	83	4.61	0.641	0.070	65.613	< .001

Note: The original significance values reported as .000 have been expressed as **p < .001**, which is the accepted APA and scientific reporting convention. If these statistics correspond to questionnaire items, you can replace the **S/N** column with the actual item statements or variable names for a more informative presentation.

Notes: T=t-test value, p<.05 (2-tailed test)

Scale for items: 5=strongly agree, 4=agree, 3=neutral, 2=disagree, 1=strongly disagree

The t-test analysis in Table 4.6 provides insights into the degree of use and perceived effectiveness of ICT-based instructional technologies in enhancing science activities. The overall mean scores for each item range from 4.08 to 4.67 on a five-point scale, indicating strong agreement among teachers about the positive impact of these technologies on their teaching practices.

Across all items, the significance level remained at 0.000, indicating strong statistical significance for each measure. These results collectively suggest that teachers recognised and affirmed the substantial impact of ICT-based instructional technologies in improving the effectiveness, accessibility, and adaptability of science activities in their classrooms.

4.2.4 ICT-based instructional technologies regulate actions and interactions of activities in the teaching of science.

This section presents data on the rules and guidelines that shape the actions and interactions in science teaching activities involving ICT-based instructional technologies. The results of the seven QIs are presented in Tables 4.7 and 4.8, respectively.

Table 4.7: Rules that regulate actions and interactions of activities in the teaching of science (N=83)

Items	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
13. The use of ICT-based instructional technologies in science teaching supports the teacher in designing science activities that could be delivered through various technologies.	31 (37.3%)	47 (56.6%)	5 (6.0%)	0 (0%)	0 (0%)
14. The use of ICT-based instructional technologies in science teaching allows the teacher to provide adequate instructions to the learner in science activities, study techniques, and some form of reference for a learner who needs help dealing with the science activities.	22 (26.5%)	46 (55.4%)	15 (18.1%)	0 (0%)	0 (0%)
15. The use of ICT-based instructional technologies in science teaching allows the teacher to evaluate what is learned, whether through electronically	44 (53.0%)	11 (13.3%)	24 (28.9%)	2 (2.4%)	2 (2.4%)

submitted assignments and/or portfolios.					
16. The use of ICT-based instructional technologies in science teaching allows the teacher to plan science activities that will help develop higher-order cognitive skills in the students.	50 (60.2%)	30 (36.1%)	1 (1.2%)	0 (0%)	2 (2.4%)
17. The integration of ICT-based instructional technologies fosters teacher-student interaction in teaching science.	34 (41.0%)	36 43.4%)	9 (10.8%)	2 (2.4%)	2 (2.4%)
18. ICT-based instructional technologies in teaching science give teachers opportunities to answer learner questions and clarify issues at any time.	45 (54.2%)	26 (31.3%)	10 (12.0%)	2 (2.4%)	0 (0%)
19. Effective teacher-content interaction through ICT-based instructional technologies enables teachers to teach basic skills to the learner (i.e., thinking skills, problem-solving skills).	29 (34.9%)	43 (51.8%)	11 (13.3%)	0 (0%)	0 (0%)

QI 13 asked respondents whether the use of ICT-based instructional technologies in science teaching supports teachers in designing science activities that can be delivered through various technologies. Regarding the question, 31 (37.3%) respondents strongly agreed, and 47 (56.6%) agreed. Overall, 78 (93.9%) respondents strongly agreed that the use of ICT-based instructional technologies in science teaching supports teachers in designing science activities that can be delivered through various technologies (Table 4.9).

QI 14 asked respondents whether the use of ICT-based instructional technologies in science teaching allows the teacher to provide adequate instruction to students on science activities and study techniques, and to serve as a reference for students who need help with the science activity. Given that, 22(26.5%) respondents strongly agreed with 46(55.4%) agreeing to the question. To this end, 68 (81.9%) respondents strongly agreed and agreed that the use of ICT-based instructional technologies in science teaching allows the teacher to provide adequate instruction to learners on science activities and study techniques, and to serve as a reference for learners who need help with the science activity.

QI 15 asked respondents whether the use of ICT-based instructional technologies in science teaching enables teachers to evaluate what learners learn, through electronically submitted assignments and/or portfolios. To this end, 44 (53.0%) respondents strongly agreed, and 11 (13.3%) agreed with the question. Hence, 55 (66.3%) strongly agreed and decided that the use of ICT-based instructional technologies in science teaching allowed the teacher to evaluate what learners learn, whether through electronically submitted assignments and/or portfolios.

QI 16 asked respondents to rate the extent to which the use of ICT-based instructional technologies in science teaching enabled teachers to plan science activities that help develop learners' higher-order cognitive skills. Given that, 50(60.2%) respondents strongly agreed with 30(36.1%) agreeing to the question. Overall, 80 (96.3%) strongly agreed and agreed that the use of ICT-based instructional technologies in science teaching enabled teachers to plan science activities that help develop students' higher-order cognitive skills.

QI 17 asked respondents whether the integration of ICT-based instructional technologies fosters teacher-learner interaction in teaching science. To this end, 34 (41.0%) respondents strongly agreed, and 36 (43.4%) agreed with the question. About 70 (84.4%) respondents strongly agreed or agreed that the integration of ICT-based instructional technologies fosters teacher-student interaction in teaching science.

QI 18 asked respondents to rate the extent to which the use of ICT-based instructional technologies in teaching science gave teachers opportunities to answer student questions and clarify issues at any time. Given that, 45(54.2%) respondents strongly agreed, with 26(31.3%) agreeing with the statement. To this end, 71 (85.5%) respondents strongly agreed and agreed that the use of ICT-based instructional technologies in teaching science enables teachers to answer students' questions and clarify issues at any time.

QI 19 asked respondents whether effective teacher-content interaction through ICT-based instructional technologies enabled teachers to teach basic skills to students (i.e., thinking skills, problem-solving skills). To this end, 29(34.9%) respondents strongly agreed, with 43(51.8%) agreeing to that statement. Thus, 72 (86.7%) respondents strongly agreed and agreed that effective teacher-content interaction through ICT-based instructional technologies enables teachers to teach basic skills to students.

Table 4.8: T-test on the rules that regulate actions and interactions of activities in the teaching of science.

S/N	N	Mean (M)	Standard Deviation (SD)	Standard Error (SE)	t-value	p-value (2-tailed)
1	83	4.31	0.583	0.064	67.421	< .001
2	83	4.08	0.666	0.073	55.842	< .001
3	83	4.12	1.064	0.117	35.288	< .001
4	83	4.54	0.650	0.071	63.702	< .001
5	83	4.18	0.899	0.099	42.362	< .001
6	83	4.37	0.792	0.087	50.315	< .001
7	83	4.22	0.663	0.073	57.903	< .001

Notes: T=t-test value, $p<.05$ (2-tailed test)

Scale for items: 5=strongly agree, 4=agree, 3=neutral, 2=disagree, 1=strongly disagree

The t-test results in Table 4.7 assessed the level of agreement among teachers regarding the rules governing actions and interactions in science teaching when using ICT-based instructional technologies. The results displayed consistently high mean scores, ranging from 4.08 to 4.54 on a five-point scale, indicating strong agreement among teachers on the positive impact of ICT-based rules in structuring science activities and enhancing classroom interactions.

The results indicate a consistent pattern of statistically significant agreement among teachers, confirming that they value ICT-based rules as instrumental in organising and optimising the instructional environment in science teaching. This consensus supports the integration of ICT guidelines in educational settings, as teachers recognised the positive effects of these structured approaches on learner interactions, instruction delivery, and the overall classroom dynamic in science teaching.

4.2.5 ICT-based instructional technologies on the functions and tasks of participants in the activity

The data presented in Table 4.9 relate to the seven QIs regarding participants' responses to their levels of various functions and tasks in the science activity.

Table 4.9: Functions and tasks of participants in the science activity (N=83)

Items.	Strongly agree	Agree	Neutral	Strongly disagree	Disagree
20. The use of ICT-based instructional technologies in science teaching changes the teacher's role from being the focal point in the learners' learning process to a facilitator, a scaffolder, or a mentor.	24 (28.9%)	45 (54.2%)	12 (14.5%)	0 (0%)	2 (2.4%)
21. ICT-based instructional technologies in science teaching foster the teachers' ability to increase	26 (31.3%)	45 (54.2%)	10 (12.0%)	0 (0%)	2 (2.4%)

student active participation in their learning process (e.g., through problem-based teaching, individual or group presentation).					
22. The use of ICT-based instructional technologies in science teaching enables the teacher to teach learners the requisite skills to discover and explore new knowledge on their own.	24 (28.9%)	55 (66.3%)	4 (4.8%)	0 (0%)	0 (0%)
23. The use of ICT-based instructional technologies for science teaching permits teachers to provide the learners with necessary supports to connect/link one science task/activity to	28 (33.7%)	43 (51.8%)	12 (14.5%)	0 (0%)	0 (0%)

another according to their own needs.					
24. The use of ICT-based instructional technologies enhances science teaching in schools.	29 (34.9%)	50 60.2%)	2 (2.4%)	0 (0%)	2 (2.4%)
25. The use of ICT-based instructional technologies allows teachers to present the students with multiple entry and exit points to learning in science teaching.	46 (55.4%)	31 37.3%)	6 (7.2%)	0 (0%)	0 (0%)
26. The use of ICT-based instructional technologies in science teaching allows teachers to provide students with limitless ways of creating their own knowledge.	28 (33.7%)	44 (53.0%)	8 (9.6%)	1 (1.2%)	2 (2.4%)

QI 20 asked respondents whether the use of ICT-based instructional technologies in science teaching alters the teacher's role from being the focal point in the learners' learning process to a facilitator, scaffolder, or mentor. Given that, 45(54.2%) respondents agreed, with 24(28.9%) strongly agreeing with the statement. Overall, 69 (83%) respondents strongly agreed and agreed that the use of ICT-based instructional technologies in science teaching shifts the teacher's role from the focal point in the students' learning process to a facilitator, scaffolder, or mentor.

QI 21 asked respondents to rate the extent to which the use of ICT-based instructional technologies in science teaching fosters teachers' ability to increase students' active participation in their learning process. Given that, 45(54.2%) respondents agreed, with 26(31.3%) strongly agreeing to the question. To this end, 71(85.5%) respondents strongly agreed and agreed that the use of ICT-based instructional technologies in science teaching fosters teachers' capacity to increase students’ active involvement in their learning process.

QI 22 asked respondents whether the use of ICT-based instructional technologies in science teaching enabled the teacher to teach learners the requisite skills to discover and explore new knowledge on their own. In this regard, 55(66.3%) respondents agreed, with 24(28.9%) strongly agreeing to the statement. Overall, 79 (95.2%) respondents strongly agreed and agreed that the use of ICT-based instructional technologies in science teaching enables teachers to impart to students the necessary abilities to independently find and investigate new information.

QI 23 asked respondents whether the use of ICT-based instructional technologies for science teaching enabled teachers to provide learners with the necessary supports to connect/link one science task/activity to another according to their own needs. To this end, 43(51.8%) respondents agreed, with 28(33.7%) strongly agreeing to the question. In total, 71 (85.5%) respondents strongly agreed and agreed that the use of ICT-based instructional technologies for science teaching enables teachers to provide learners with the necessary supports to connect one science task/activity to another according to their own needs.

QI 24 asked respondents to rate the extent to which the use of ICT-based instructional technologies enhanced science teaching in schools. Given that, 50 (60.2%) respondents agreed, with 29(34.9%) strongly agreeing with the question. To this end, 79 (95.1%) respondents strongly agreed and decided that the use of ICT-based instructional technologies enhances science teaching in schools.

QI 25 asked respondents whether the use of ICT-based instructional technologies allowed teachers to present learners with multiple entry and exit points for learning in science. To this end, 46(55.4%) respondents strongly agreed, with 31(37.3%) agreeing with the statement. Overall, 77 (92.7%) respondents strongly agreed or agreed that the use of ICT-based instructional technologies allows teachers to present learners with multiple entry and exit points for learning in science.

QI 26 asked respondents to rate the extent to which the use of ICT-based instructional technologies in science teaching allowed teachers to provide learners with limitless ways to create their own knowledge. Given that, 44 (53.0%) respondents agreed, with 28 (33.7%) strongly agreeing. To this end, 72 (86.7%) respondents strongly agreed and agreed that the use of ICT-based instructional technologies in science teaching allows teachers to provide learners with limitless ways to create their own knowledge (Table 4.8).

Table 4.10: T-test with respect to the functions and tasks of participants in the science activity.

S/N	N	Mean (M)	Standard Deviation (SD)	Standard Error (SE)	t-value	p-value (2-tailed)
1	83	4.07	0.808	0.089	45.903	< .001
2	83	4.12	0.802	0.088	46.784	< .001
3	83	4.24	0.532	0.058	72.669	< .001
4	83	4.19	0.671	0.074	56.930	< .001
5	83	4.25	0.730	0.080	53.085	< .001
6	83	4.48	0.632	0.069	64.638	< .001
7	83	4.14	0.828	0.091	45.583	< .001

Notes: T=t-test value, $p<.05$ (2-tailed test)

Scale for items: 5=strongly agree, 4=agree, 3=neutral, 2=disagree, 1=strongly disagree**.**

Table 4.10 presents the results of a t-test comparing various functions and tasks performed by participants during an activity. A total of 83 individuals participated, with mean scores across the different functions and tasks ranging from 4.07 to 4.48. The standard deviations varied slightly, reflecting the spread of scores around the mean, with values ranging from 0.532 to 0.828. The standard error of the mean, which indicates how accurately the sample mean estimates the population means, was consistently low across all functions, ranging from 0.058 to 0.091.

The t-values were notably high, ranging from 45.583 to 72.669, suggesting significant differences in scores for each function or task relative to the hypothesised mean. Each t-test yielded a p-value of .000, indicating that the results were statistically significant at any conventional alpha level and providing strong evidence that the participants' evaluations of the functions and tasks were not due to random chance. Overall, the data underscores the effectiveness of the activity, as participants consistently rated the functions and tasks positively, as evidenced by the high means and significant t-test results.

Although the quantitative results show quantifiable trends in ICT usage and perceptions, the qualitative findings provide a deeper understanding of how teachers perceive and understand these patterns. The following section, therefore, complements the statistical outcomes by contextualising them within teachers' lived classroom realities.

4.3. QUALITATIVE RESULTS

This section presents the qualitative findings derived from eight open-ended survey questions, analysed to complement and contextualise the quantitative results. In line with the anonymity protocols outlined in Chapter 1 (section 1.7.2), no participant's name appeared in any document used during the discussion sessions, thereby safeguarding confidentiality. Thematic analysis revealed four major themes: Structural Barriers, Pedagogical Benefits of ICT, Teacher Capacity and Training, and Policy and Curriculum Pressures, which situate teacher perspectives within the broader activity system and help explain the statistical trends. To ensure credibility and rigour, the interpretation was guided by Activity Theory, which provides a systemic lens for analysing teachers' perceptions of ICT integration. Activity Theory emphasises the dynamic interaction between subjects (teachers), objects (science teaching and learning activities), mediating artefacts (ICT tools), rules (institutional and policy frameworks), community (peer and learner collaboration), and division of labour (roles of teachers and learners).

The findings are therefore presented in alignment with both the Activity Theory components and the themes identified in Phase 5 of the analysis. For example, Structural Barriers and Policy Pressures correspond to the rules and division of labour shaping ICT use; Teacher Capacity and Training reflect the subject–tool interaction; Pedagogical Benefits of ICT align with the object/outcome of improved science learning; and Social Influence is embedded within pedagogical benefits, corresponding to the community dimension of Activity Theory. The headings and subheadings in this chapter therefore make both the themes and Activity Theory elements visible, ensuring that the data presentation is theoretically grounded while remaining faithful to the voices of participating teachers (see Table 4.11).

Table 4.11: Alignment of Phase 5 Themes with Activity theory Components in the context of Qualitative results.

Phase 5 Theme	Activity Theory Component	Examples from Data	Relevant Headings from the Qualitative Results
Theme 1: Structural Barriers	**Rules & Division of Labour** (institutional policies, infrastructural constraints)	Limited access to ICT labs, unreliable electricity, poor broadband connectivity	- 4.3.1 Theme 1: Structural Barriers - 4.3.1.1 Experience at present school
Theme 2: Teacher Capacity and Training	**Subject–Tool Interaction** (teachers as subjects, ICT as mediating tools, training shaping use)	Ease/difficulty of ICT use, confidence levels, training needs	- 4.3.2 Theme 2: Teacher Capacity and Training - 4.3.2.1 Subject taught
Theme 3: Pedagogical Benefits of ICT	**Object / Outcome** (goal of activity system: improved science learning, learner-centred engagement)	Enhanced teaching, learner-centred roles, cooperative learning, virtual experiments	- 4.3.3 Theme 3: Pedagogical Benefits of ICT - 4.3.3.1 Mode of teaching in facilitation of science learning - 4.3.3.2 Experience of using ICT-based instructional technologies - 4.3.3.3 Using ICT-based instructional technologies to improve learning of science activities - 4.3.3.4 Using ICT-based instructional technologies to regulate actions and interactions of activities

Phase 5 Theme	Activity Theory Component	Examples from Data	Relevant Headings from the Qualitative Results
			- 4.3.3.5 ICT tools that mediate science learning - 4.3.3.6 Learners' roles in science activities
Theme 4: Policy and Curriculum Pressures	**Rules & Division of Labour** (curriculum demands, institutional rules, policy expectations)	Curriculum completion pressures, institutional rules, national ICT policy expectations	- 4.3.4 Theme 4: Policy and Curriculum Pressures
Theme 5: Social Influence	**Community** (peer collaboration, learner encouragement, collective practices)	Peer collaboration, learner encouragement, cooperative learning	- Incorporated within 4.3.3.3 (Community: cooperative learning opportunities) - 4.3.3.6 Learners' roles in science activities (Community: peer-to-peer teaching, learner encouragement)

Note: Theme 4: Social Influence is embedded within Theme 3

4.3.1 Theme 1: Structural Barriers (Rules and Division of Labour)

Despite the benefits, teachers identified significant structural barriers. Limited access to ICT laboratories, unreliable electricity, and poor broadband connectivity constrained effective integration. Many schools lacked sufficient devices, forcing teachers to rely on basic applications. These infrastructural challenges were particularly acute in rural Mpumalanga schools, limiting the sustainability of ICT use.

4.3.1.1 Experience at present school

Regarding teaching experience, the data (see Table 4.12) revealed that a significant number of participants (38) had 10 years of teaching experience, whereas few (22) had 5 years, and 20 had 8 years. The least number (3) had less than 5 years of teaching experience in their present schools. This implies that the participants in this study comprised a significant level of seasoned expertise within the group. However, acknowledge any limitations, such as self-report bias or sample representativeness, that could affect the generalizability of these findings, to address potential reader concerns about validity.

Table 4.12: Teaching Experience of Participants

Teaching Experience	Frequency
10 years	38
8 years	20
5 years	22
Less than 5 years	3

4.3.2 Theme 2: Teacher Capacity and Training (Subject–Tool Interaction)

Findings revealed varying levels of teacher competence in ICT use. While some teachers were comfortable with basic applications, many lacked confidences in integrating advanced instructional technologies. Teachers emphasised the need for ongoing professional development and training to build digital literacy and pedagogical skills. Without adequate training, ICT adoption remained superficial and restricted to administrative tasks.

4.3.2.1 Subject taught

The data as presented in Table 4.13 indicates the majority of the participants (53) to be teaching physical science and natural science subjects, as compared to the least number of participants who were in the subject groups of physical science and mathematics (15), physical science and life sciences (8), physical science and technology (3), Physical science and life orientation (1), and Physical science and Math literacy (3). This implies that the participants comprised experts and professionals within the field under study. The data is illustrated in Table 4.12.

Table 4.13: Subjects Taught by Participants

Subject Combination	Frequency
Physical science & Natural science	53
Physical science & Mathematics	15
Physical science & Life science	8
Physical science & Technology	3
Physical science & Life orientation	1
Physical science & Math literacy	3

4.3.3 Theme 3: Pedagogical Benefits of ICT (Object / Outcome)

Teachers consistently highlighted the pedagogical value of ICT tools in science classrooms. They reported that ICT enhanced learner engagement, supported diverse teaching strategies, and facilitated higher-order thinking. Examples included using smartboards to visualise abstract concepts and computers to provide timely feedback. These benefits reinforced ICT's role in promoting learner-centred approaches and improving science instruction.

4.3.3.1 Mode of teaching in facilitation of science learning

With regard to the extent to which ICT is used in science teaching to support science learning, the results in Table 4.14 revealed that a majority of teachers (60) used ICT-based methods to support their students' science learning. Thus, a considerable amount of ICT integration occurred in the science classrooms of the participants in this study. On the other hand, 23 participants also used more traditional methods of teaching and learning science in their classrooms, i.e., the chalkboard and textbooks. `The finding that 60 teachers use ICT-based methods to facilitate science learning aims to inspire educators and policymakers by emphasising the widespread adoption and perceived value of ICT in science instruction.

Table 4.14: Modes of Teaching Used

Mode of Teaching	**Frequency**
ICT-based methods	60
Chalkboard & textbooks	23

4.3.3.2 Experience of using ICT-based instructional technologies

The participants were further probed about their experience with ICT-based instructional technologies for teaching science before their employment at the current schools. As illustrated in Table 4.15, the majority of teachers (55) reported having excellent experience with ICT in teaching science before their employment at the current school. This suggests that the participants in this study were experts in the use of ICT-based instructional technologies for learning science.

Table 4.15 Participants' prior experience in using ICT-based instructional technologies

Question	Responses	Frequency
What is your experience of using ICT-based instructional technologies for teaching science before you became a teacher in this school?	'Excellent/excellent experience of utilising ICT'	53
	'I have Limited experience.'	4
	'Have no experience.'	25
	'Poor experience'	1

4.3.3.3 Using ICT-based instructional technologies to improve learning of science activities

In response to the question of how ICT-based instructional technologies improve the teaching of science activities, about 46 of 83 participants mentioned that ICT-based instructional technologies 'enhanced teaching and learning.', whereas, 6 of the participants explained that ICT-Based instructional technologies 'provides easy access to surf information,' and four explaining that they 'allow teachers to cover more topics in a short space of time.' The reasons could be that 'learners can learn anytime', and 'at their own pace'. It was also noted from the participants that these technologies are 'effective' as it 'allows cooperative learning, development of technology skills' as learners in this regard can multitask 'seamlessly'. In other words, the technologies 'enhance knowledge retention' as they help 'students to understand the content in a more practical way. These findings underscore the pedagogical value of ICT in enriching science instruction and promoting learner-centred approaches (Table 4.16).

Table 4.16: How ICT-based instructional technologies improve the teaching of science activities Question	**Response**	**Frequency**
1	Enhanced teaching and learning	46
2	Exposed learners to knowledge	2
3	Helps develop learners' thinking skills	1
4	Provides easy access to surf information	6

Table 4.16: How ICT-based instructional technologies improve the teaching of science activities Question	Response	Frequency
5	Learners can learn anytime	3
6	Learners can learn at their own pace	2
7	Allows teachers to cover more topics in a short space of time	4
8	Enhances knowledge retention	1
9	Effective	1
10	Allows cooperative learning	1
11	Allows development of technology skills	1
12	Multitasking is possible and seamless	1
13	Helps students understand content in a more practical way	1
14	Prompt feedback	5
15	Improvement is big	1
16	Allows teachers to have more time with learners	1
17	Allows prompt support where required	1
18	Allows teachers to select activities that accommodate diverse learners	1
19	More clarity from experts	1
20	Flexible; adjustments can be made quickly	1
21	Using simulation	1
22	Never used it	1
Using ICT-based instructional technologies for teaching science, how does it improve the teaching of science activities?	'It practically enhances teaching and learning.'	46
	Provides easy access to surf information online. '.	7
	'Allows cooperative learning.'	10
	'It allows teachers to provide prompt support to students where required.'	19
	'Never used it.'	1

4.3.3.4 Using ITC-based instructional technologies to regulate actions and interactions of activities

Regarding how participants regulate actions and interactions in science activities when using ICT-based technologies, the data in Table 4.17 revealed that about 48 participants explained how they easily restrict their actions and interactions through these technologies by selecting activities that accommodate the diverse learners' needs. This implies that the use of ICT-based instructional technologies helps teachers to regulate actions and interactions during science activities. Despite 14 participants who reported not regulating actions and interactions with ICT-based technologies, other participants reported allowing learners to use past questions, doing experiments, interacting with learning content, and using strict instructions to avoid divergence. This means that teachers employ a variety of ICT-supported instructional strategies to manage classroom activities, promote meaningful learner engagement, and ensure that interactions remain aligned with the intended science learning outcomes

Table 4.17: ICT-based instructional technologies regulate actions and interactions of science activities

Question	Responses	Frequency
	1. By allowing them to use Past Question 3 2. Didn't regulate 3. Doing experiment 4. Allowing them to interact with learning contents 5. easily done Through technology 6. Used strict instructions to avoid divergence	3 14 2 2 48 2
When using ICT-based instructional technologies to teach science, how do you regulate actions and interactions during instruction?	'Actions and interactions are easily regulated through the technology by selecting activities that accommodate the diverse learners' needs.'	48
	'Didn't regulate.'	14
	'Allowing them to interact with learning contents.'	2
	'Doing experiment'	14

	'Used strict instructions to avoid divergence.'	2
	'By allowing them to use Past Question.'	3

4.3.3.5 ICT tools that mediate science learning

A range of ICT-based technologies were found to be used by teachers to teach Science concepts. From the data in Table 4.18, about 32 out of 83 teachers mentioned tools such as smartboards used in their lessons. This was followed by 30 teachers who confirmed using computers in their teaching and learning, while other teachers reported using past exam papers, online platforms, and cellphones. To support the use of smartboards as a technology tool for teaching, a teacher noted that, "*Smartboard allows for the illustration of complex science concepts to make abstract concepts more concrete for learners*." This means that teachers perceive smartboards as an effective pedagogical tool for simplifying abstract scientific concepts through visual and interactive representations.

Table 4.18: ICT Tools Used in Science Teaching

ICT Tool	**Frequency**
Smartboard	32
Computer	30
Cellphone/Tablet	6
Online platforms	7
Past exam papers	8

4.3.3.6 Learners' roles in science activities

When asked about the roles learners play in ICT-based instructional activities, the data in Table 4.19 revealed that when other learners were not sure of their roles, almost 68 participants, having reported that learners took on active roles in learning and even creating knowledge and understanding concepts in different ways than traditional resources. Participants further explained that learners will download question papers, interact with teachers, and engage in demonstrations and illustrations of various science concepts. This suggests that the use of ICT-based instructional technologies transforms the teaching of science from teacher-centred to learner-centred. This notion was elaborated by participants, *"Learners are no longer passive.*

With ICT, they take ownership of their learning, exploring concepts and even teaching each other." This idea suggests that using ICT in Science lessons would increase learners' concentration and to learn more faster than before.

Table 4.19: Learners' Roles in ICT-Based Science Activities

Learner Role	**Frequency**
Active engagement & knowledge creation	68
Downloading question papers	3
Interaction with the teacher during ICT lessons	3
Demonstration & illustration	3
Increased concentration & quick learning	1
Explaining abstract concepts	1
Not sure	4

4.3.4 Theme 4: Policy and Curriculum Pressures (Rules & Division of Labour)

Teachers noted that institutional rules, curriculum demands, and policy expectations shaped their ICT practices. National ICT policies encouraged integration, but classroom realities often lagged. Pressure to complete curriculum requirements sometimes discouraged experimentation with ICT-based methods. Teachers also reported that policy support was not always matched with adequate resources, creating tension between expectations and practice. Another key factor affecting the extent to which teachers integrated ICTs into their classroom activities was the institutional (school-based) contexts, that is, physical settings, available resources, and policies within which teachers work. Most of the participating schools in the study had installed smartboards and computers in classrooms, which the teachers utilized for the completion of a host of ICT-based science activities and lessons. Some teachers also had access to their personal cellphones and laptops, as well as their students' devices, to complete science ICT activities and lessons in schools and at home.

Theme 5: Social Influence (Community): Social Influence emerged, particularly in relation to peer collaboration and learner encouragement. Although Social Influence is not presented as a standalone theme, it is embedded within Pedagogical Benefits because teachers described cooperative learning and peer expectations as integral to the pedagogical value of ICT. For instance, as shown in Table 4.16, one teacher emphasised that ICT "allows cooperative learning", while others highlighted that it "provides prompt support to students where required." Similarly, Table 4.19 illustrates how learners themselves became active agents, with teachers noting that "learners are no longer passive… they take ownership of their learning, exploring concepts and even teaching each other." These statements demonstrate that peer collaboration and learner encouragement were central to how teachers perceived the pedagogical benefits of ICT, thereby embedding Social Influence within this theme.

4.4. CHAPTER SUMMARY

This chapter presented the findings from both the quantitative and qualitative data on the evaluation of ICT-based instructional technologies to facilitate science learning. The quantitative results began with participants' demographic information, followed by descriptive and inferential analyses of their use of ICT tools. The qualitative findings were then introduced to complement and contextualise these results, with data presented in tables and figures that illustrated teacher and learner perspectives.

The thematic analysis revealed five major themes: Structural Barriers, Teacher Capacity and Training, Pedagogical Benefits of ICT, Policy and Curriculum Pressures, and Social Influence. Interpreted through the lens of Activity Theory, these themes highlighted the systemic dynamics shaping ICT integration. Structural barriers and policy pressures reflected the rules and division of labour that constrained practice; teacher capacity and training illustrated the subject–tool interaction; pedagogical benefits aligned with the object/outcome of improved science learning; and social influence corresponded to the community dimension, emphasising peer collaboration and learner encouragement.

Overall, the results revealed gaps in the diversity of ICT-based instructional technologies employed in science classrooms. Addressing these gaps by supporting teachers to use a broader set of tools, alongside strengthening access, training, and institutional support, would make ICT integration more transformative. The findings underscore that the more teachers employ diverse technologies to facilitate science activities, the more learner-centred and collaborative the process becomes.

CHAPTER 5

THE STUDY'S DISCUSSIONS, LIMITATIONS, AND RECOMMENDATIONS

5.1. INTRODUCTION

The chapter details the findings and themes from the previous chapters. It also discusses the study's potential limitations that may have affected its findings and proposes areas for further research in the field. The chapter concludes with numerous recommendations for further research. The purpose of the study, as explained in Chapter 1, Section 1.3.2 of this examination, was to evaluate ICT-based instructional technologies to facilitate science learning. The primary research question, as well as the secondary research questions, were:

How do teachers perceive the integration of ICT-based instructional technologies in the activities of the science subject?

The study's sub-questions were as follows:

1. What types of ICT-based instructional technologies are used by teachers to mediate activities in teaching science, and how can these inform future policy and training programmes?
2. To what extent are ICT-based instructional technologies integrated into science teaching practices?
3. What contextual, institutional, and policy-related factors influence the integration of ICT-based instructional technologies in science classrooms?
4. How do teachers and learners interact with ICT tools within the science teaching activity system?

This part is divided into three sections. The researcher firstly summarises the key findings of the research regarding the evaluation of ICT-based instructional technologies to facilitate science learning. Secondly, the recommendations are presented for evaluating ICT-based instructional technologies to enable science learning for science educators, policymakers, and for additional research in this field? Lastly, the part concludes with an end to the investigation.

5.2. THE STUDY’S SUMMARY

This segment of the study presents a detailed summary of all five chapters:

Chapter 1 provided a detailed discussion of the study's background, in which the researcher explained the context of the study. Research questions and their sub-questions were developed in this chapter since every study must address a research question. The study clearly explains the reasons for its uniqueness compared to previous studies. This chapter provided an overview of the theoretical frameworks, the research strategy and methodology, and a preliminary survey of the literature. The chapter mentioned that Chapter 2 includes the literature review and the study's underlying theory. Under the research methodology, the processes of data collection and analysis, population selection and sampling. In Chapter 3, steps to guarantee trustworthiness were compiled for discussion. Because one of this study’s requirements was to collect data from individuals employed by professional institutions, ethical considerations were crucial in this chapter. As a result, the study took into account the importance of obtaining university approval and participant consent. No study is without limitations, so this chapter discusses the study's limitations and how the researcher addressed them.

Chapter 2 presented the literature review and the study's theoretical framework in detail. A global review of the literature on integrating ICT-based instructional technologies into science activities was conducted, with a focus on South Africa. Furthermore, a detailed review was performed with a clear focus on teachers’ acceptance of ICT-based instructional technologies, the factors influencing that acceptance, and the benefits of such technologies in Science Education. This chapter also presents barriers to integrating ICT-based instructional technologies and the institutional roles of ICT in Science Education. Moreover, the Unified Theory of Acceptance and Use of Technology (UTAUT) framework, formulated by Venkatesh et al. (2003), is outlined, and the rationale for the choice is justified.

Chapter 3 dealt with the data-collection process, including site selection and the tools utilised. An online survey, consisting of closed- and open-ended questions, was identified and discussed as a data-collection instrument. The collected data were analysed using both quantitative and qualitative approaches, as discussed in detail in this chapter.

Chapter 4 discussed the study's findings and their interpretation. The goal of the interpretation was to provide the participants with a condensed voice without sacrificing their authenticity. Tables and charts were used to illustrate and qualify the participants' experiences of the phenomenon.

5.3. DISCUSSION OF FINDINGS

The purpose of this study was to investigate teachers' perceptions of integrating ICT-based teaching technologies into science activities. This section discusses the findings on the integration of ICT-based instructional technologies in science classrooms in Mpumalanga Province. By situating the findings within the Activity Theory, the analysis highlights how mediating tools, institutional rules, and participant roles collectively shape classroom practice.

5.3.1. SQ1: What types of ICT-based instructional technologies are used by teachers to mediate activities in teaching science, and how can these inform future policy and training programmes?

The findings revealed a preference among teachers for digital and interactive tools, with computers and smartboards (44.58%; $p < .001$) serving as the primary resources for teaching science. The qualitative findings support this pattern, as most teachers identified computers and smartboards as their primary instructional tools. This suggests that while ICT integration exists, it is mainly limited to a narrow range of technologies. This finding is consistent with studies showing that teachers in relatively better-resourced schools often have access to basic ICT infrastructure (Mhlanga & Moloi, 2020). Thus, supporting the integration of science and technology into teaching is significant to education (Ogegbo, 2024). Therefore, regardless of their location, age, gender, or socioeconomic status, all educators have a duty to employ ICT in teaching and learning in the networked, knowledge-based society (Mukhari, 2016).

The finding confirms Engeström's (1996) notion that computers and smartboards act as the main mediating artefacts within the activity system. In this study, computers and smartboards are tools teachers use to mediate science instruction. The dominance of computers and smartboards suggests that ICT integration in the sampled schools is largely hardware-centred rather than pedagogically diversified. While these tools provide foundational digital support, the limited use of collaborative platforms, simulation software, and mobile-based tools indicates a relatively narrow interpretation of ICT integration. This aligns with findings from Pelser and Swanepoel (2022), who observed that many South African schools equate ICT use with the presence of devices rather than with instructional transformation. From an Activity Theory perspective, the tools component appears constrained, limiting the potential for the activity system to expand toward more innovative science learning practices.

5.3.2. SQ2: To what extent are ICT-based instructional technologies integrated into science teaching practices?

Engeström (1996) illustrates how ICT tools transform the nature of science activities by expanding what teachers and learners can achieve within the learning system. Based on this theoretical lens, this study found that ICT-based instructional technologies improve science activities. The results have confirmed these: ICT allows science teaching to take place anytime and anywhere and provides access to teaching materials regardless of location (97.6%); enhances the delivery of science activities (96.4%); and, overall, improves science teaching (94.0%). The t-test analysis confirmed these findings, with high mean scores across all items and statistically significant results ($p <.001$).

Qualitative data corroborate these results, with teachers reporting that ICT enhances practical learning, supports cooperative learning, enables prompt feedback, and provides easy access to online resources. These results are consistent with the literature, which recognises ICT as a potent instrument for enhancing teaching and learning processes by fostering active engagement and flexible education (Prenjasi & Ahmetaga, 2015). Research also confirms that ICT is particularly effective in Science Education because it supports visualisation, simulation, and inquiry-based learning (Agyemang-Adarkwah et al., 2024; Bishaw et al., 2022). This suggests that technology is central to effective science instruction in contemporary classrooms (Ogegbo, 2024).

The overwhelmingly positive percentages suggest robust teacher endorsement of ICT-based instructional technologies. However, it is crucial to analyse these findings beyond superficial consensus. A high level of statistical significance does not always indicate a significant change in teaching methods. The findings indicate that teachers acknowledge the significance of ICT in improving science activities. However, the extent to which this translates into sustained, innovative classroom practices may be contingent upon contextual and institutional factors.

According to Tondeur et al. (2017), positive perceptions alone are not enough for long-term integration. There must also be coherent policy implementation, ongoing professional development, and stable infrastructure.

5.3.3. SQ3: What contextual, institutional, and policy-related factors influence the integration of ICT-based instructional technologies in science classrooms?

According to Engeström (1996), ICT shapes the "rules" of the activity system by structuring how tasks are performed, how learners interact, and how instruction is delivered. In this study, it was found that ICT-based instructional technologies enable flexible design (93.9%), the delivery of science activities and interactions across multiple platforms (81.9%), and the provision of clear instructions for science activities, study techniques, and reference materials for further support (96.3%). All items recorded statistically significant results ($p < .001$).

This discovery aligns with studies showing that technology-based learning tools support lesson organisation, interaction, and learner engagement, particularly in Science Education (Fakherji, 2019; Polly et al., 2021; Zandri & Harisman, 2025). The results suggest that Science Education is uniquely positioned to benefit from integrating ICT-based instructional technologies, given its emphasis on experimentation, abstract concepts, and process skills. Qualitative findings reinforce these results, with most teachers indicating that ICT makes it easier to regulate classroom interactions by accommodating diverse learner needs. However, a minority reported difficulties in regulating activities, suggesting that effective ICT use depends on teacher competence and classroom management skills.

Several studies on the use of technology-based learning tools have supported the view that successful ICT integration requires more than technical proficiency; it requires meaningful pedagogical application (Alt, 2018; Fakherji, 2019; Polly et al., 2021; Zandri & Harisman, 2025). From an Activity Theory perspective, these findings highlight the regulatory function of "rules" within the activity system. Institutional expectations, curriculum demands, and workshop structures appear to shape how ICT is operationalised in science classrooms. Where such rules are supportive and aligned with pedagogical goals, ICT integration becomes facilitative; however, where they are ambiguous or weakly implemented, integration may remain procedural rather than transformative. This indicates that ICT adoption is not solely dependent on teacher willingness but is embedded within broader systemic and policy-driven structures.

5.3.4. SQ4: How do teachers and learners interact with ICT tools within the science teaching activity system?

Various studies (Serevina et al., 2018; Savec, 2020) have confirmed that ICT-rich classrooms allow learners to actively participate in their own education and promote self-regulation, metacognition, and ownership of the learning process. Furthermore, platforms such as Google Classroom, Moodle, and Microsoft Teams provide spaces where learners can access resources, submit assignments, engage in discussions, and receive real-time feedback (Serevina et al., 2018; Savec, 2020).

In this study, the qualitative findings revealed that ICT-based instructional technology is shifting teacher responsibilities from traditional instruction to roles as supporters, facilitators and mentors in the learning process. From a learner engagement perspective, ICT tools provide a more interactive and learner-centred learning environment. Unlike traditional teacher-led instruction, ICT-based technologies enhance active learner participation, develop self-directed learning skills, and encourage exploration of new knowledge. This aligns with Mnisi et al. (2024), who highlight that teachers now value the use of ICT-based instructional technologies, incorporating them into classrooms to increase learner participation and make the learning process more engaging.

With the aid of ICT-based instructional technologies, teachers can take learners beyond traditional limits, ensure adequate participation in teaching and learning processes, and create vital environments for experimentation and exploration (Onwunr, 2020). The growing use of ICT resources in classrooms enables learners to take initiative of their education by enhancing comprehension and conceptual understanding. These findings suggest a gradual shift toward greater digital competence among science teachers, reflecting evolving expectations in contemporary educational environments.

Within the framework of the Activity Theory, this change reflects a reconfiguration of the division of labour within the classroom activity system. ICT-based instructional technologies redistribute instructional authority by encouraging collaborative knowledge construction rather than unilateral knowledge transmission. However, while the findings indicate movement toward learner-centred engagement, the sustainability of this shift depends on teachers continued professional growth and institutional support. Without systemic reinforcement, changes in classroom roles may remain incremental rather than fully transformative.

Overall, the discussion demonstrates that ICT-based instructional technologies are well-received and functionally integrated into science classrooms in Mpumalanga Province. However, their effectiveness is mediated by contextual rules, institutional structures, and evolving participant roles within the classroom activity system. The findings, therefore, contribute to understanding ICT integration not merely as tool adoption, but as a systemic process shaped by interconnected elements of practice. Sustainable transformation in Science Education will require alignment between teacher readiness, infrastructural capacity, policy coherence, and pedagogical innovation.

5.4. RECOMMENDATIONS

After carefully examining the data and comprehending its significance the researcher makes the following recommendations:

- The participating teachers' levels of technology competency vary; therefore, the Department of Education should offer professional development programs that equip Science teachers with the necessary skills and knowledge for teaching in a modern classroom environment.
- The dominance of computers and smartboards as the primary ICT tools suggests a constrained mediation process, potentially limiting the richness of science learning experiences. School Governing Bodies should augment resources to improve ICT tools in schools, including mobile devices, projectors, and online platforms.
- The study was conducted in Mpumalanga Province using a small sample, further studies employing a larger sample across multiple provinces and comparing science teachers in Mpumalanga with those in other provinces are recommended.

5.5. THE STUDY'S LIMITATIONS

This study, like any other, had a few perceptible limitations:

- Firstly, this study was conducted with Physical Sciences teachers in Mpumalanga Province of South Africa. A sample size of 83 science teachers participated in the survey, so the research could not include all Physical Sciences teachers in South Africa. Considering the nine provinces of South Africa, this study is not representative of the entire country, as schools across provinces and districts may vary in their ICT policies and how they are implemented.
- Secondly, the study focused on evaluating ICT-based instructional technologies to facilitate science activities in Mpumalanga Province, using a small sample of 83 teachers. So, it might not accurately reflect the entire educational community, since the education system encompasses a range of subjects.
- Thirdly, this research focused on secondary school science educators, so it might not represent the entire country's education system.
- A limitation of this study is the risk of theoretical overcrowding from employing three frameworks (UTAUT, TPB, and Activity Theory) while relying on a single teacher centred data source. Also, the community aspects of the activity theory framework were primarily interpreted through the lens of the subject (teachers), as the data collection instruments were teacher-centred and did not directly capture perspectives from other stakeholders such as learners, administrators, or policymakers.
- Lastly, participants were not interviewed directly; they responded to an open-ended questionnaire at their convenience and from different sites. Ideally, follow-up interviews with selected teachers could have yielded deeper insights.

5.6. CONTRIBUTIONS OF THE STUDY

This study makes both empirical and conceptual contributions to the field of Science Education and ICT integration in South Africa. Empirically, it provides context-specific evidence from Mpumalanga Province, a region that is underrepresented in ICT-in-education research. By focusing on Physical Sciences teachers in rural and peri-urban contexts, the study expands the understanding of how ICT integration unfolds in structurally constrained environments. Conceptually, the study contributes to the application of Activity Theory to the examination of

ICT integration in science classrooms. Rather than treating technology adoption as an isolated behaviour, the study demonstrates how mediating tools, institutional rules, and division of labour interact within a dynamic classroom activity system. This systemic interpretation advances discourse beyond simplistic measures of ICT access or usage frequency. Methodologically, the mixed-methods case study design provides an integrated perspective that combines statistical trends with contextual insights, thereby strengthening the robustness of findings within similar educational settings.

This study also advances knowledge and practice in Science Education by providing empirical evidence on how teachers perceive and use ICT-based instructional technologies to facilitate science learning in Mpumalanga Province. By showing that teachers mainly rely on computers and smartboards as mediating tools, the study highlights both progress and gaps in ICT integration, especially the limited diversity of tools used in science classrooms. This contribution is significant because it moves the discussion beyond general claims about technology use. It also presents a clearer picture of which tools are actually used, how they are applied, and the degree to which teachers trust that they improve access to materials, lesson delivery, and learner engagement. In addition, the findings strengthen the understanding of teacher acceptance and use of ICT in Science Education. The study also confirms that teachers view ICT as valuable for improving science activities, enabling flexible teaching, supporting instruction, and encouraging more active participation among learners.

The study has implications for educational theory, policy, and practice. Theoretically, it supports the relevance of the Unified Theory of Acceptance and Use of Technology (UTAUT) by showing that teachers' perceived utility, usability, and institutional backing are closely linked to the integration of ICT into science activities (Venkatesh, 2003). In terms of policy, the findings suggest that government and education authorities should not only provide ICT infrastructure but also ensure that technical support and professional development are consistent across schools, as limited competence and uneven access can limit ICT use to a few tools. For practice, the study indicates that schools and science departments should promote the use of a broader range of ICT tools such as simulations, online discussion platforms, and digital assessment tools, since teachers reported that ICT improves lesson delivery, promotes interaction, and shifts teaching towards learner-centred learning. Overall, this study contributes to improving ICT integration by informing teacher training programmes, guiding resource allocation, and supporting policies that strengthen technology-supported science teaching and learning in South African schools.

5.7. CHAPTER SUMMARY

This study aimed to evaluate ICT-based instructional technologies in facilitating science activities. This effect was investigated through data collection from participants. Mixed-method research used closed and open-ended online surveys, and 83 Physical Sciences teachers took part in the study. The data analysis revealed that the use of ICT-based instructional technologies has favourable effects on science activities.

The study participants confirmed that ICT-based instructional technology brings flexibility and new possibilities to science instruction. ICT-based instructional technology enables teachers to interact with students anytime, anywhere, without barriers to learning. It was also found that the use of ICT-based instructional technology is valuable for improving science activities and enables teachers to employ teaching strategies suited to learners' needs. The findings of the study agree with researchers who posit that integration of technology has a positive impact on Science Education. Consequently, this conclusion is compelling for all science teachers: they should receive more training and develop the capability to integrate ICT-based instructional technologies into their teaching.

Furthermore, the study found that teachers regard ICT-based instructional technologies as beneficial for creating structured, interactive, and responsive learning environments in Science Education, thereby enhancing both instructional flexibility and learner support. It was also found that ICT-based instructional technology is shifting teacher responsibilities from traditional instruction to roles as facilitators, mentors, and supporters in the student learning process. In this view, the teachers used ICT-based instructional technologies, such as computers, smartboards, and simulations. This study concludes that the utilisation of ICT-based instructional technologies in science teaching enhances active student participation, develops self-directed learning skills, and promotes the exploration of new knowledge.

The implications of these findings are significant for Science Education practice, policy, and teacher development. The results suggest that ICT-based instructional technologies are no longer optional tools but necessary components of effective science teaching in contemporary classrooms. By shifting teachers' roles from traditional transmitters of knowledge to facilitators, mentors, and supporters of learning, ICT promotes learner-centred instruction, active participation, and the development of self-directed learning skills. The study also suggests that sustained professional development is necessary to ensure that all science teachers acquire the competence and confidence to meaningfully integrate ICT, rather than relying on a limited range of tools. At the policy level, the findings highlight the necessity of sustained investment not only in ICT infrastructure but also in training, technical support, and equitable access across schools. Overall, this study reinforces the view that effective integration of ICT-based instructional technologies can transform science teaching and learning, improve learner engagement and understanding, and better prepare students to engage in a society that is heavily reliant on technology.

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APPENDIX A

Link to online Survey/Questionnaires

https://www.surveymonkey.com/r/qr_code/X7SQP75

APPENDIX B

QR-Code to online survey

APPENDIX C

Consent letter

consent letter used
2024.pdf

APPENDIX D

Ethical Clearance Certificate

Ethical certificate.pdf

APPENDIX E

Letter of permission from the Mpumalanga Department of Education

Dept of Edu data
collection approval.pc

APPENDIX F

Screenshot of SPSS