

**Exploring the Integration of Education for  
Sustainable Development through  
Information and Communication Technology in  
Mathematics Education  
Master's Dissertation**

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## **KEYWORDS**

- ❖ Education for Sustainable Development (ESD)
- ❖ Information and Communication Technology (ICT)
- ❖ Sustainable Development Goals (SDGs)
- ❖ Mathematics Education
- ❖ ICT Integration
- ❖ ESD Integration
- ❖ Curriculum and Assessment Policy Statement (CAPS)
- ❖ Professional Development
- ❖ Transformative Learning
- ❖ Technologically Enhanced and Sustainable Mathematical Knowledge (TESMK)

## ABSTRACT

This study investigates how Education for Sustainable Development (ESD) can be integrated into mathematics teaching through Information and Communication Technology (ICT) in South African secondary schools. Despite global emphasis on aligning education with sustainability goals, little is known about how ICT facilitates ESD integration in mathematics classrooms, particularly in resource-constrained contexts.

Guided by Nerstrom's Transformative Learning Model and Msafiri's ICT Integration Framework, the study adopted a qualitative multiple case study design. Data were collected through focus group discussions, classroom observations, and post-observation interviews with eight mathematics teachers from three peri-urban schools in the Pinetown district of KwaZulu-Natal.

Findings revealed that teachers were largely unaware of ESD and the United Nations' Sustainable Development Goals (SDGs). While ICT use in mathematics teaching was limited and primarily focused on visualisation, some sustainability concepts were unintentionally incorporated. Professional development for ESD integration through ICT was inadequate, constrained by systemic gaps in support, resources, and time.

The study proposes a conceptual framework, Technologically Enhanced and Sustainable Mathematical Knowledge (TESMK), highlighting the intersection of mathematical, technological, and sustainability knowledge as critical for meaningful integration. It recommends targeted professional development, improved infrastructure, and policy reforms to advance ICT-enabled ESD in mathematics, offering actionable insights for educators and policymakers in resource-limited contexts.

**Keywords:** Education for Sustainable Development (ESD); Information and Communication Technology (ICT); Sustainable Development Goals (SDGs); Mathematics Education; TESMK.

# Table of Contents

KEYWORDS .....	i
ABSTRACT.....	ii
LIST OF FIGURES .....	vii
LIST OF TABLES .....	viii
LIST OF ABBREVIATIONS.....	ix
DECLARATION .....	xii
ACKNOWLEDGEMENTS.....	xiii
Chapter 1   Introduction .....	1
1.1 INTRODUCTION AND BACKGROUND TO THE STUDY.....	1
1.2 PROBLEM STATEMENT.....	2
1.3 AIM OF THE STUDY.....	4
1.3 RATIONALE OF THE STUDY .....	5
1.4 SIGNIFICANCE OF THE STUDY.....	6
1.5 LOCATION OF THE STUDY .....	7
1.6 RESEARCH OBJECTIVES .....	7
1.7 RESEARCH QUESTIONS .....	7
1.8 THEORETICAL FRAMEWORK.....	8
1.9 RESEARCH METHODOLOGY.....	9
1.10 STRUCTURE OF THE DISSERTATION .....	9
1.12 DEFINITION OF TERMS.....	11
1.13 CONCLUSION .....	13
Chapter 2   Literature Review & Theoretical Framework .....	14
2.1. INTRODUCTION .....	14
2.2. LITERATURE REVIEW .....	14
2.2.1 Education for Sustainable Development (ESD) .....	15
2.2.1.1 Definition and Principles of ESD.....	15
2.2.1.2 State of ESD in South Africa .....	17
2.2.1.2 State of ESD in South Africa.....	17
2.2.1.2.1 Policy Framework for ESD .....	17
2.2.1.2.2 Current ESD Initiatives in South Africa.....	18
2.2.1.2.3 Challenges and Gaps in ESD Implementation .....	19
2.2.2 Information and Communication Technology (ICT) in Mathematics.....	20

2.2.2.1 ICT Tools and Resources for Mathematics Teaching .....	20
2.2.2.1 International Perspectives on ICT Tools in Mathematics .....	20
2.2.2.2 ICT Integration in South Africa: Contextual Realities .....	21
2.2.2.3 Barriers to ICT-Supported ESD Integration .....	21
2.2.2.4 Opportunities for ICT Integration in Mathematics .....	22
2.2.2.2 Strategies for ICT Integration in ESD .....	22
2.2.3.3 Impact of ICT Integration .....	25
2.2.3 Teachers and ICT-supported ESD .....	27
2.2.3.1 Teacher Awareness and Perspectives .....	27
2.2.3.2 Professional Development for ICT and ESD .....	34
2.2.3.2.1 Global Insights on PD Models for ESD-ICT Integration .....	36
2.2.4 Summary and Implications .....	38
2.3. THEORETICAL FRAMEWORKS .....	39
2.3.1. ICT Integration Framework .....	40
2.3.2. Nerstrom’s Transformative Learning Model .....	44
Chapter 3   Methodology .....	48
3.1 INTRODUCTION .....	48
3.2 RESEARCH PARADIGM .....	50
3.3 RESEARCH DESIGN .....	50
3.4 SAMPLING STRATEGY .....	51
3.5. DATA-GENERATION METHODS .....	54
3.5.1 Focus Group Discussions .....	54
3.5.2 Professional Development (PD) .....	55
3.5.3 Observation .....	56
3.5.4 Post-observation interviews .....	57
3.5.4 Data Analysis .....	58
3.6 VALIDITY AND RELIABILITY .....	61
3.6.1 Credibility .....	61
3.6.2 Transferability .....	62
3.6.3 Dependability .....	62
3.6.4 Confirmability .....	62
3.6.5 Audit Trail .....	63
3.6.6 Strategies to Enhance Credibility .....	63
3.7 ETHICAL CONSIDERATIONS .....	63

3.8	CONCLUSION.....	65
Chapter 4   Data Presentation & Analysis.....		66
4.1.	INTRODUCTION .....	66
4.2.	AWARENESS AND UNDERSTANDING OF ESD.....	69
4.2.1	Understanding of Sustainability Concepts .....	70
4.2.2	ESD Integration in Practice .....	72
4.2.3	Benefits of ESD/Sustainability infused mathematics lessons .....	77
4.2.4	Challenges to effective ESD integration through ICT.....	81
4.3.	ICT INTEGRATION IN MATHEMATICS TEACHING .....	88
4.3.1	School-based challenges.....	96
4.3.2	Other Challenges .....	105
4.4.	PROFESSIONAL DEVELOPMENT FOR TEACHERS .....	106
4.5.	CONCLUSION.....	115
Chapter 5   Discussion and Conclusion .....		119
5.1	INTRODUCTION .....	119
5.2	FINDINGS PERTAINING TO RESEARCH QUESTION 1.....	119
5.2.1	Awareness and Understanding of ESD .....	119
5.2.2	Teachers’ Implicit Integration of ESD .....	120
5.2.3	Perceived Benefits of ESD Integration.....	121
5.2.4	Barriers to Effective ESD Integration .....	122
5.3	FINDINGS PERTAINING TO RESEARCH QUESTION 2.....	126
5.3.1	ICT Tools Teachers Use.....	126
5.3.2	Barriers to Effective Use of ICT.....	127
5.4.1	Teachers’ Experiences with Professional Development .....	132
5.5	LIMITATIONS.....	139
5.6	RECOMMENDATIONS.....	139
5.6.1	For Policymakers.....	139
5.6.2	For Schools .....	140
5.6.3	For Teacher Training Programmes.....	140
5.6.4	For Future Research.....	140
5.7	CONCLUSION.....	141
BIBLIOGRAPHY.....		144
APPENDIXES .....		168
	Appendix A: Principal consent letter and declaration.....	168

Appendix B: Educator consent letter and declaration.....	172
Appendix C: The participants’ qualifications .....	176
Appendix D: Focus Group Discussion schedule.....	177
Appendix E: Observation schedule .....	180
Appendix F: Post-Observation interview schedule.....	184
Appendix G: Ethical clearance certificate from UKZN.....	186
Appendix H: Parent/ Guardian consent letter and declaration.....	187
Appendix I: Learner Consent Letter and Declaration .....	190
Appendix J: Permission letter from DBE.....	193
Appendix K: Turnitin similarity report .....	194
Appendix L: Letter from Editor .....	195

## LIST OF FIGURES

Figure 2.1: ICT Integration Framework adapted from Msafiri et al. (2023, p. 13) .....	41
Figure 2.2: Nerstrom’s Transformative Learning Model (Nerstrom, 2014, p.328) .....	44
Figure 3.1: The Interconnection between Research Paradigm, Research Design, and Sampling Strategy .....	53
Figure 3. 2 The Data Generation Process .....	58
Figure 4.1: The Intersection of ESD and Mathematics.....	69
Figure 4.2: Participant 2’s Lesson on Measurements .....	78
Figure 4.3: Participant 1’s Lesson Plan Snapshot.....	84
Figure 4.4: Intersection of Mathematical Knowledge and Technological Knowledge (Source: Author’s own illustration).....	95
Figure 4.5: Emerging Conceptual Framework: Technologically Enhanced and Sustainable Mathematical Knowledge (TESMK) (Source: Author’s own illustration).....	117

## LIST OF TABLES

Table 1. 1 Definition of key terms .....	11
Table 2.1: Alignment of Msafiri’s ICT Integration Framework with the Research Questions .....	43
Table 2.2: Alignment of Msafiri’s ICT Integration Framework and Nerstrom’s Transformative Learning Model.....	46
Table 4.1: Alignment of Themes and Subthemes with the Research Questions and the Theoretical Frameworks.....	66
Table 4.2: The Participants’ Biographical Details.....	68
Table 3.1: Linking Research Questions, Instruments Method, Research Instrument and Analysis .....	49
Table 3.2: The participants’ characteristics.....	54
Table 5. 1 Summary of Research Questions, Key Findings, Discussion, and Recommendations .....	137
Table 3.1: Linking Research Questions, Instruments Method, Research Instrument and Analysis .....	49
Table 3.2: The participants’ characteristics.....	54
Table 5. 1 Summary of Research Questions, Key Findings, Discussion, and Recommendations .....	137

## LIST OF ABBREVIATIONS

ATP	Annual Teaching Plan
CAPS	Curriculum and Assessment Policy Statement
CAS	Computer Algebra System
CSSF	Collaborative Structure Search Framework
DBE	Department of Basic Education
DGS	Dynamic Geometry Software
DMS	Dynamic Mathematics Software
EE	Environmental Education
EFA	Education For All
ESD	Education for Sustainable Development
FET	Further Education and Training
FGD	Focus Group Discussion
4IR	Fourth Industrial Revolution
ICT	Information and Communication Technology
KZN	KwaZulu-Natal
LMS	Learning Management System
NCS	National Curriculum Statement
NEEP	National Environmental Education Program

PAL	Peer Assisted Learning
PCK	Pedagogical Content Knowledge
PD	Professional Development
SADC	Southern African Development Community
SD	Sustainable Development
SDGs	Sustainable Development Goals
SKU-HSTM	Source–Knowledge–Use and Humanities–Science–Technology Model
SMK	Sustainable Mathematical Knowledge
SSD	Social Sustainable Development
STEM	Science, Technology, Engineering and Mathematics
TAD	Thematic Data Analysis
TESD	Teacher Education for Sustainable Development
TESMK	Technologically Enhanced and Sustainable Mathematical Knowledge
TPACK	Technological, Pedagogical and Content Knowledge
TSA	Technological Sustainability Assessment
TVET	Technical and Vocational Education and Training
UAE	United Arab Emirates
UKZN	University of KwaZulu-Natal
UN	United Nations

UNESCO United Nations Educational, Scientific and Cultural Organization

WESSA Wildlife and Environment Society of South Africa

## DECLARATION

I, **Mziwendoda Dzanibe**, declare that:

### **Exploring the Integration of Education for Sustainable Development through Information and Communication Technology in Mathematics Education**

is my own and has not been submitted, either in full or in part, for the fulfilment of degree requirements at this or any other higher education institution. To the best of my knowledge, the thesis does not contain any material published or written by another individual, except where proper citations have been provided.



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22/04/2025  
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**Date**

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# Chapter 1 | Introduction

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## 1.1 INTRODUCTION AND BACKGROUND TO THE STUDY

This study explores the integration of Education for Sustainable Development (ESD) into mathematics teaching through Information and Communication Technology (ICT) in South African secondary schools. This chapter presents the background to the study, outlines the problem statement, research objectives and questions, and briefly discusses the theoretical frameworks and research methodology. It concludes with an overview of the dissertation structure. This study aims to explore how Education for Sustainable Development (ESD) can be integrated into mathematics teaching through Information and Communication Technology (ICT) in South African secondary schools.

Sustainable Development (SD) gained global prominence through the United Nations' Brundtland Report in 1987 and has since become central to policy agendas worldwide (Diaz-Lopez et al., 2021). In 2015, the United Nations adopted 17 Sustainable Development Goals (SDGs) under the theme "Transforming our world: The 2030 Agenda for Sustainable Development" (Diaz-Lopez et al., 2021). ESD, embedded within SDG 4 (Quality Education), is regarded as a catalyst for achieving all other SDGs by equipping learners with knowledge, skills, and values for sustainable living (UNESCO, 2024).

In South Africa, achieving equitable, inclusive, and quality education remains constrained by systemic challenges such as inconsistent policy and funding priorities, limited teacher training, and curriculum overload (Zickafoose et al., 2024). Various national initiatives aim to embed sustainability into education, including Environmental Education (EE) mandates, STEM-focused strategies, and policy documents like the Curriculum and Assessment Policy Statement (CAPS). CAPS encourages mathematics teaching to promote "critical awareness of how mathematical relationships are used in social, environmental, cultural, and economic relations" (DoE, 2011, p. 8).

Mathematics education is particularly critical for advancing ESD, as it develops learners' analytical and problem-solving abilities needed to address sustainability challenges. In the South African context, mathematics provides opportunities to engage learners with issues such as resource management, financial literacy, and environmental conservation.

Embedding ESD into mathematics supports learners in applying abstract concepts to real-world contexts, fostering critical thinking and preparing them for informed, sustainable action in their communities.

## **1.2 PROBLEM STATEMENT**

The United Nations' 2030 Agenda for Sustainable Development envisions a future that features justice and prosperity within environmental limits, and inclusive equity, and that holds education in high regard as stated in Sustainable Development Goal 4 (Kioupi & Voulvoulis, 2019). In their article, Kioupi and Voulvoulis (2019) stated that education is seen as key to achieving the other goals given that sustainability is the goal for education. As South Africa is a signatory of the UN (Benjamin & Adu, 2019), it carries a duty to take an active role in the realisation of the SDGs which can be done through ESD. South African education is found to be geared towards ESD, and such an orientation may be responsive to the country's challenges like unemployment, HIV/Aids, poor living conditions, and persistent environmental degradation (Zickafoose et al., 2024; Teise & Le Roux, 2016).

Furthermore, one of the specific aims of mathematics, as prescribed by the CAPS document, is that content should involve contextual problems related to social, health, cultural, scientific, political, economic and environmental issues, where possible (DoE, 2011, p. 8). Apart from the noted need to integrate ESD within mathematics education (as it is in other subjects) in order to prepare students for the challenges of sustainable living and global citizenship, there remains a significant gap in the literature about the effective use of ICT to promote this integration.

In South Africa, where there is pressure on the curriculum to incorporate ESD principles into all school subjects (Benjamin & Adu, 2019; Teise & Le Roux, 2016), teachers may be lacking the necessary training, knowledge and resources to effectively employ ICT for this purpose. These systemic barriers constrain teachers' capacity to embed sustainability meaningfully into mathematics classrooms and hinder innovation in pedagogy. This may also be worsened by insufficient Professional Development opportunities tailored to equip teachers with the skills and knowledge required to integrate ESD into their teaching

practices through ICT, as is the case in other parts of the world (Waltner et al., 2020). Additionally, the actual implementation of these practices in the classroom remains underexplored, with little evidence available on the outcomes and effectiveness of such integration in the South African context.

Furthermore, there are limited studies that speak to the integration of ESD in mathematics through ICT. Instead, ESD and ICT are noted in isolation of each other, ignoring the impact of ICT in facilitating this integration. This study aimed to help address these shortcomings by exploring the extent to which mathematics teachers in the Pinetown district can utilise ICT to integrate ESD principles into their teaching, identifying the benefits and challenges associated with these practices, and offering insights into how Professional Development programmes can be enhanced to better support teachers in this critical area.

The preliminary literature review showed that, if mathematics teachers do not integrate ESD into their teaching, the disconnect between policy and practice will be maintained which is unsustainable. However, if ESD is integrated into mathematics in the absence of ICT, the integration may take longer or fail completely. Ultimately, mathematics will not be contributing much towards producing members of society who are conscious of sustainability and are aware of their role in sustainable development. As a result, learners remain underprepared to engage with complex socio-economic and environmental issues, limiting their ability to act as informed, responsible citizens in a rapidly changing world. These problems are the motivation behind this study.

Addressing this gap is important because it has both theoretical and practical significance. Theoretically, exploring the integration of ESD through ICT in mathematics teaching can enrich current academic understanding by linking two fields (sustainability education and digital pedagogy) that are often treated separately. It can therefore contribute to the limited body of knowledge on how ICT can act as a catalyst for sustainable development in subject-specific contexts like mathematics.

Practically, this research can guide teachers, school leaders, and policymakers by providing actionable strategies for integrating ESD through ICT in real classrooms. It can inform the design of Professional Development programmes that equip teachers with both the digital skills and pedagogical approaches needed to make ESD meaningful and relevant in mathematics. In a context like that of South Africa, where ICT access and sustainable development education are both evolving, this study offers timely insights that can support more effective curriculum implementation and educational equity while equipping learners with critical thinking and problem-solving skills to address sustainability challenges in their communities.

### **1.3 AIM OF THE STUDY**

The aim of this study is to explore how Education for Sustainable Development (ESD) can be integrated into mathematics teaching through the use of Information and Communication Technology (ICT) in South African secondary schools, with a particular focus on peri-urban contexts. Specifically, the study seeks to:

- Investigate mathematics teachers' understanding and conceptualisation of ESD and its relevance to mathematics education.
- Examine the current practices of integrating ICT in mathematics teaching and how these practices can support the inclusion of ESD principles.
- Identify the challenges and opportunities experienced by mathematics teachers when attempting to incorporate ESD into their teaching through ICT.
- Explore the extent to which teachers are supported through professional development, access to resources, and institutional policies in their efforts to integrate ESD and ICT in mathematics teaching.

This aim is guided by the broader objective of contributing to pedagogical innovations that promote sustainable development in education and support the achievement of Sustainable Development Goal 4 (Quality Education).

### 1.3 RATIONALE OF THE STUDY

The researcher's professional experiences across diverse educational contexts highlighted the need for this study. During primary, secondary, and tertiary education in South Africa, exposure to Information and Communication Technology (ICT) in mathematics classrooms was minimal. Lessons remained teacher-centred, with little emphasis on integrating digital tools to enhance learning. Even as an undergraduate teacher-in-training, ICT use was limited to producing assignments rather than fostering pedagogical innovation.

As a qualified educator teaching mathematics and computer science in South Africa, ICT integration in practice was constrained by limited infrastructure and resources. While tools such as projectors and laptops enhanced lesson delivery, they did not enable meaningful learner engagement with technology. Challenges such as lack of internet connectivity and minimal institutional support further hindered effective ICT use.

A contrasting experience emerged while teaching mathematics in the United Arab Emirates (UAE), where ICT integration was mandatory and fully supported at systemic levels. Access to advanced technologies, consistent professional development opportunities, and alignment with national goals enabled transformative teaching practices. Exposure to learners actively engaging with the United Nations Sustainable Development Goals (SDGs) underscored the potential for education to promote sustainability awareness from an early age.

These experiences prompted critical reflection on the South African education system, where policy frameworks such as the Curriculum and Assessment Policy Statement (CAPS) emphasise sustainability in mathematics but provide little guidance on practical implementation. Moreover, existing literature tends to examine either Education for Sustainable Development (ESD) or ICT in isolation, with limited research on how ICT can facilitate ESD integration in mathematics teaching (Bascopé et al., 2019; Basson, 2023; Munasi, 2024; Parry & Metzger, 2023).

This study addresses this gap by exploring how ICT can support mathematics teachers in integrating ESD principles into their pedagogy. By investigating teacher awareness,

instructional practices, and the support systems available, the research provides theoretical insights and practical recommendations for enhancing sustainability education through ICT in resource-constrained contexts.

#### **1.4 SIGNIFICANCE OF THE STUDY**

The findings of this study present the current state of ESD integration through ICT in mathematics teaching and provide insight into curriculum alignment with sustainability principles. The study also highlights key challenges faced by teachers, such as limited training and inadequate infrastructure, which hinder effective ESD and ICT integration. Addressing these challenges can guide stakeholders in developing targeted interventions, such as designing context-specific professional development programmes and investing in ICT infrastructure to support sustainability-focused pedagogy.

An emerging conceptual model from this study offers a framework for understanding the intersection of mathematics, sustainability, and digital tools. This model can inform curriculum designers and policymakers in revising educational frameworks to embed ESD meaningfully within mathematics teaching. Teacher training institutions could adopt these insights to integrate ESD and ICT modules into pre-service and in-service teacher education programmes.

This research contributes methodologically by demonstrating the value of qualitative multiple case studies in capturing nuanced teacher experiences across diverse school contexts. Future studies can build on this approach to explore longitudinal impacts of professional development interventions or compare rural and urban contexts.

Ultimately, this study benefits multiple stakeholders. Mathematics teachers gain strategies for fostering critical thinking, sustainability awareness, and digital literacy in learners. School leaders and policymakers can use the findings to design and implement systemic support mechanisms. Learners stand to benefit the most, as enhanced teaching practices prepare them with essential skills for addressing real-world sustainability challenges in the 21st century.

## **1.5 LOCATION OF THE STUDY**

This study formed part of a larger project, and its scope was framed within the Pinetown district in KwaZulu-Natal Province, South Africa. The study targeted three schools from peri-urban areas. Such areas are characterised by the poor quality of life on the outskirts of the cities (urban areas) where non-white South Africans (predominantly black) were placed by the apartheid government (Giombini & Thorn, 2022; Macagnano, 2002). The three schools that were selected are from the same district and subscribe to the same curriculum. The schools are homogeneous in terms of the country, province, district, curriculum, and annual teaching plans while they also have some contextual differences. These schools are classified as quantile<sup>1</sup> 1 to 3 schools.

## **1.6 RESEARCH OBJECTIVES**

This research study sought to achieve the following objectives:

- To explore mathematics teachers' awareness and understanding of integrating Education for Sustainable Development (ESD) into mathematics instruction through the utilisation of Information and Communication Technology (ICT).
- To investigate how teachers in the Pinetown district employ ICT tools and strategies to support the integration of ESD principles into mathematics teaching.
- To examine the types and extent of institutional and systemic support available to facilitate the integration of ESD into mathematics teaching through ICT.

## **1.7 RESEARCH QUESTIONS**

To achieve the objectives of this exploration, this study intended to respond to the following main research questions:

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<sup>1</sup> Quantiles refer to a classification of all public schools in South Africa for allocation of resources where quantile 1 to 3 are usually no-fee schools found in peri-urban areas while quantile 4 to 5 schools are found in urban areas and charge fees (Maistry, 2020; Grant, 2013).

- To what extent are mathematics teachers aware of the integration of ESD into mathematics instruction through the use of ICT, and how does this awareness influence their teaching practices?
- How do teachers in the Pinetown district employ ICT tools and strategies to integrate ESD principles into mathematics education?
- What institutional and systemic support is available to teachers to enable the integration of ESD into mathematics teaching through ICT, and how effective is this support?

## **1.8 THEORETICAL FRAMEWORK**

This study discusses the integration of ESD through ICT into mathematics teaching. Two compatible frameworks were adopted to understand how each integration is supposed to be carried out and to guide the analysis of data collected. Nerstrom's Transformative Learning Model was used to understand the ESD integration while Msafiri's ICT integration framework was used to understand the integration of ICT into mathematics teaching.

Nerstrom's Transformative Learning Model was instrumental in framing how teachers' awareness and understanding of ESD could evolve through critical reflection and engagement with sustainability principles. This model provided a lens to analyse how mathematics teaching might shift from traditional approaches to practices that empower learners as active agents of change.

Msafiri's ICT Integration Framework complemented this perspective by offering practical dimensions for evaluating how ICT tools are used in classroom settings. It guided the exploration of infrastructure, teacher competencies, and pedagogical strategies necessary for effective technology integration in mathematics.

Together, these frameworks created a coherent analytical foundation, allowing the study to examine both the conceptual underpinnings of ESD integration and the technological mechanisms enabling it. Their combined use ensured that findings addressed both the

transformative potential of sustainability education and the practical realities of ICT-supported teaching in the South African context.

## **1.9 RESEARCH METHODOLOGY**

In this study, the interpretivist paradigm was used as research approach to allow the researcher to treat the context as unique while considering the associated circumstances and study participants (Alharahsheh & Pius, 2020). Hence, the examination of Multiple Case Studies was used to gain an in-depth understanding the phenomena being studied. Moreover, interpretivist researchers are concerned with the reality that is based on the subjective experiences of the external world as opposed to a permanent label of an object based on its repeatedly recorded behaviour (Kumatongo & Muzata, 2021). This study sought to understand the subjective experiences of mathematics teachers in their context guided by the interpretive worldview principles.

A purposive sampling technique was used to help ensure that the sample has characteristics that will serve the study (Andrade, 2021). Furthermore, purposive sampling is known to be effective when conducting Multiple Case Studies as this allows for an in-depth focus on a phenomenon (Campbell et al., 2020; Gustafsson, 2017).

## **1.10 STRUCTURE OF THE DISSERTATION**

This research study was organised into the following five chapters:

### *Chapter 1: Introduction*

This chapter introduced the background to this study. The chapter presented an overview of how the study was carried out. It briefly discussed the problem statement, rationale and location in which the study was carried out. The main objectives, research questions, theoretical frameworks, research methodology and layout of this study were also outlined.

### *Chapter 2: Literature Review and Theoretical Framework*

In this chapter, relevant literature was explored to reveal what has been written on the topic while exposing the gap in literature and practice that this study intended to fill. The theoretical underpinnings that guided the exploration and data analysis were also outlined.

### *Chapter 3: Methodology*

In this chapter, various aspects of the research methodology were discussed. This included the research paradigm, research design, sampling strategy, data-generation methods, validity and reliability, and ethical considerations.

### *Chapter 4: Presentation and Analysis*

This chapter focused on the presentation and analysis of the data. For this endeavour, reflexive thematic data analysis was employed. This chapter further saw the emergence of a potential model that could be used to understand the integration of ESD into mathematics education through ICT.

### *Chapter 5: Discussion and Conclusion*

The primary aim of this chapter was to present the key findings of the study. This was followed by recommendations based on the data analysis.

## 1.12 DEFINITION OF TERMS

Table 1.1 presents definitions of key terms used in this study. These definitions provide conceptual clarity and ensure consistent understanding of terminology related to Education for Sustainable Development (ESD), Information and Communication Technology (ICT), and their integration within mathematics education.

*Table 1. 1 Definition of key terms*

Key Term	Definition
Education for Sustainable Development (ESD)	A teaching and learning framework grounded in the core values and principles of sustainability, including human rights, poverty alleviation, sustainable living, environmental conservation, peace, democracy, public health, biodiversity, climate action, gender equity, and the safeguarding of indigenous cultures (SADC, 2022).
Information and Communication Technology (ICT)	Encompasses a range of digital tools and resources used for communication, content creation, information sharing, storage, and management. In education, it involves leveraging software applications, internet-based tools, multimedia content, and digital platforms to support teaching and learning (Kramarenko et al., 2021; Mailizar & Fan, 2020; Msafiri et al., 2023).
Sustainable Development Goals (SDGs)	A collection of 17 global objectives established by the United Nations in 2015, designed to eradicate poverty, safeguard the environment, and promote peace and prosperity for everyone by 2030 (United Nations Resolution A/RES/70/1).
Curriculum and Assessment Policy Statement (CAPS)	South Africa's national curriculum framework guiding content and assessment across subjects. CAPS encourages the use of mathematics to develop a critical awareness of social, environmental, cultural, and economic issues (DoE, 2011).

Professional Development (PD)	Continuous learning and training initiatives aimed at enhancing teachers' pedagogical strategies, subject expertise, and technological capabilities (particularly for integrating ESD using ICT tools) (Msafiri et al., 2023; Olawumi & Mavuso, 2024).
Transformative Learning	A learning theory developed by Mezirow and simplified by Nerstrom, focusing on how learners (in this case, teachers) change their perspectives through critical reflection on their experiences (Nerstrom, 2014).
ICT Integration Framework	A model developed by Msafiri et al. (2023), illustrating components and interactions required for effective ICT integration, including Professional Development, school leadership support, and alignment with curriculum goals.
Technologically Enhanced and Sustainable Mathematical Knowledge (TESMK)	An emerging concept introduced in this study, representing the intersection of mathematical knowledge, sustainability knowledge, and technological knowledge. It describes the ideal knowledge base required for teachers to integrate ESD into mathematics teaching through ICT.
Education for Sustainable Development (ESD)	A teaching and learning framework grounded in the core values and principles of sustainability, including human rights, poverty alleviation, sustainable living, environmental conservation, peace, democracy, public health, biodiversity, climate action, gender equity, and the safeguarding of indigenous cultures (SADC, 2022).

## **1.13 CONCLUSION**

This chapter presented an overview of this dissertation. This included a brief discussion of the background, problem statement, rationale, and location of the study. The research objectives, research questions, theoretical underpinnings of the study, and research methodology were also outlined. Lastly, the layout of the five chapters of the dissertation was presented. The next chapter examines existing literature and theoretical perspectives that inform this study. It focuses on Education for Sustainable Development (ESD), Information and Communication Technology (ICT), and their integration within mathematics teaching. This review highlights gaps in knowledge and practice that the study seeks to address.

# Chapter 2 | Literature Review & Theoretical Framework

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## 2.1. INTRODUCTION

Global education systems face increasing pressure to prepare learners for complex sustainability challenges, such as climate change, poverty, and rapid technological change (UNESCO, 2020; United Nations, 2015). Integrating Education for Sustainable Development (ESD) into mathematics teaching through Information and Communication Technology (ICT) is vital for equipping learners with critical thinking and problem-solving skills relevant to the 21st century (Kioupi & Voulvoulis, 2019). In South Africa, where education is marked by persistent inequalities and infrastructure limitations, this integration is particularly urgent to support national development goals and address global sustainability imperatives (Zickafoose et al., 2024).

The main purpose of this chapter is to discuss literature on the integration of ESD into mathematics teaching through ICT, particularly in the South African context. In addition, global and local initiatives that seek to promote ESD through ICT will be discussed. This will be followed by a discussion of the two compatible theoretical frameworks to offer lenses through which the integration of ESD and ICT can be understood for the purpose of this study.

## 2.2. LITERATURE REVIEW

This section commences with the definition of ESD and an overview of its core principles. This is followed by an overview of studies about the state of ESD in South Africa, which includes the policy framework, current initiatives, challenges and opportunities. An overview of ICT tools and resources for mathematics teaching is provided, highlighting current tools and integration challenges. This section also presents strategies and approaches for integrating ESD into mathematics through ICT from around the world. Furthermore, a review of studies on teachers' perspectives about the use of ICT for ESD in

mathematics will be undertaken. This component focuses on insights from surveys or interviews, the typical challenges that teachers are facing, and teachers' Professional Development needs. The documented impact of ICT on ESD awareness and practices, both locally and internationally, will also be described. Lastly, this section will review various literature sources on the provision of Professional Development for the integration of ESD and ICT in mathematics.

## **2.2.1 Education for Sustainable Development (ESD)**

This subsection provides an overview of Education for Sustainable Development (ESD), outlining its definition, core principles, and global significance. It also examines the state of ESD in South Africa, highlighting national policies, initiatives, and contextual challenges influencing its implementation in mathematics education. Understanding these foundations is essential to situate the study within broader sustainability efforts.

### **2.2.1.1 Definition and Principles of ESD**

The United Nations Educational, Scientific and Cultural Organization (UNESCO, 2002), as cited in Teise and Le Roux (2016, p. 66), defines ESD as “an emerging but dynamic concept that encompasses a new vision of education that seeks to empower people of all ages to assume responsibility for creating a sustainable future”. In a recent study on ESD in Southern Africa, ESD refers to a teaching and learning approach based on the principles and ideas that underpin sustainability (UNESCO, 2022). Olsson et al. (2022) defined ESD as education where teaching focuses on developing competences in students that allow them to solve and act on problems based on intertwined perspectives.

ESD is also defined as a tool that can be used to drive the required transformation, enabling society to reach a sustainable state (Kioupi & Voulvoulis, 2019). For Kioupi and Voulvoulis (2022), ESD is hypothesised an enabling element for the transition to a sustainable future as envisioned by the UN's Sustainable Development Goals (SDGs). For the SADC (2022), ESD is a pedagogical approach rooted in the core values of sustainability, including human rights, poverty alleviation, sustainable ways of living, peace, environmental protection,

democratic governance, health, biodiversity, climate action, gender equity, and the preservation of indigenous cultures. In a schooling context, ESD refers to all actions aimed at promoting learners' sustainability competences and shaping sustainable development (Waltner et al., 2020).

The diversity of definitions underscores the adaptability and relevance of ESD in different cultural, environmental, and socioeconomic contexts globally, illustrating its critical role in shaping sustainable futures through education (Waltner et al., 2020). This means ESD can be used to respond to the unique contextual challenges of different countries (Acevedo-Duque et al., 2023). In this study, the researcher adopted the Southern African Development Community's definition of ESD (SADC, 2022) as it speaks to the countries in the SADC region, which includes South Africa, making it more relevant.

The concept of ESD is introduced in a report of the World Commission on Environment and Development (1987) titled *Our Common Future* (also known as the Brundtland Report) (Kopnina & Meijers, 2014). In 2002, the General Assembly of the United Nations initiated the decade of ESD which is based on four principles, namely education viewed as a critical tool for Sustainable Development (SD) implementation; refocusing education on Education For All (EFA) and the Millennium Development Goals (MDG), now known as the Sustainable Development Goals; interaction and networking among stakeholders in ESD; and developing strategies to assess ESD progress (Glavič, 2020).

Various studies have indicated that ESD is an integral part of the quest to achieve SD (Kioupi & Voulvoulis, 2019; Kioupi & Voulvoulis, 2022; Teise & Le Roux, 2016; UNESCO, 2022). This education is characterised by inclusivity, collaboration, quality teaching and learning, lifelong learning, and learning that is holistic and participatory in nature. However, sub-Saharan Africa is facing various challenges in achieving equitable, inclusive and quality education due to concerns such as inconsistent policy and funding priorities, restricted access and inclusion, gender inequality, physical limitations, curriculum limitations, and insufficient teacher training (Zickafoose et al., 2024).

### **2.2.1.2 State of ESD in South Africa**

This subsection examines the current state of Education for Sustainable Development (ESD) in South Africa. It explores key policy frameworks, national initiatives, and systemic challenges affecting ESD integration within the education system. The discussion highlights how sustainability principles are embedded in South African education policies and considers barriers to their effective implementation in classroom practice, particularly in mathematics education.

### **2.2.1.2 State of ESD in South Africa**

South Africa's education system is at a critical juncture in responding to both local and global sustainability challenges. Education for Sustainable Development (ESD) offers a transformative pathway for equipping learners with the knowledge, skills, and values needed to address complex socio-environmental issues, such as poverty, inequality, and environmental degradation (UNESCO, 2020; Zickafoose et al., 2024). Embedding ESD within the South African curriculum (particularly in mathematics) holds promise for nurturing critical and reflective citizens capable of advancing sustainable development.

#### **2.2.1.2.1 Policy Framework for ESD**

In 2012, the Department of Basic Education introduced the Curriculum and Assessment Policy Statement (CAPS) to address shortcomings in the National Curriculum Statement (NCS) (Department of Planning, Monitoring and Evaluation [DPME], 2017). CAPS prescribes both the content to be taught and the pacing of instruction, supported by the Annual Teaching Plan (ATP), which guides teachers' daily practice (Naidoo, 2019).

According to the DoE (2011, p. 8), the CAPS document titled Mathematics Teaching and Learning aims to help learners develop an awareness of how mathematical relationships apply to social, environmental, cultural, and economic contexts. Furthermore, the DoE (2011) recommends the use of national surveys from Statistics South Africa (StatsSA), international surveys from the United Nations (UN Data), and other online resources to provide context for data comparison and analysis. This demonstrates how ESD principles are embedded in educational policies, even if not always explicitly stated.

Several key policies reinforce ESD principles, including the White Paper on Education and Training (1995), which emphasizes democratic governance, stakeholder involvement, interdisciplinary environmental literacy, sustainability objectives, and integrated approaches to education (Department of Education, 1995). These foundational principles have informed subsequent policies such as White Paper 6 on Inclusive Education (2001), which advocates for equity and learner empowerment, and the DBE Strategic Plan (2015/16–2019/20), aligning with Sustainable Development Goal 4 by promoting inclusive, quality education and lifelong learning.

The Draft Policy on Rural Education (2017) highlights the integration of indigenous knowledge systems and contextual responsiveness to rural communities' lived experiences. More recently, the Basic Education Laws Amendment Act (2024) codifies principles like non-discrimination, inclusive access, and participatory governance in the education sector. Collectively, these policies signal a sustained and evolving commitment to sustainability and inclusive educational transformation (Teise & Le Roux, 2016).

#### **2.2.1.2.2 Current ESD Initiatives in South Africa**

Post-1994, Environmental Education (EE) gained traction in response to global calls for sustainability integration. The South African Constitution mandates EE across all educational phases (Benjamin & Adu, 2019). The Green Paper on Environmental Policy (1996) and the White Paper on Environment and Development (1995) further promoted EE within formal education (Benjamin & Adu, 2019).

Notable initiatives include the National Environmental Education Program (NEEP) and the Eco-Schools Programme, which aimed to foster sustainability practices in schools (Lotz-Sisitka, 2011). However, while these programmes enhanced awareness, they lacked mechanisms for sustained teacher professional development and did not prioritize mathematics or ICT integration. Similarly, STEM education has been promoted as a strategy for advancing sustainable development, though challenges such as insufficient teacher training and limited resources remain (Tikly et al., 2018).

### 2.2.1.2.3 Challenges and Gaps in ESD Implementation

Despite progressive policy frameworks and initiatives, several barriers hinder effective ESD integration:

- **Teacher Capacity:** Teachers often lack the pedagogical content knowledge (PCK) necessary for embedding sustainability in mathematics instruction (Lotz-Sisitka, 2011).
- **Resource Inequality:** Public schools face overcrowding, limited ICT access, and infrastructural deficits, while private schools demonstrate more cohesive ICT-supported ESD integration (Basson, 2023).
- **Curriculum Constraints:** While CAPS advocates inclusivity, its rigid and standardised structure undermines differentiation and fails to accommodate diverse learners (Harley & Wedekind, 2004; Seedat, 2018; Neethling et al., 2023).
- **Language Barriers:** Studies show that learning in a second language (English) reduces learner comprehension, further challenging ESD integration (Taylor & Von Fintel, 2016; Tshikondela et al., 2025).

Socioeconomic factors such as poverty, unemployment, and environmental degradation exacerbate these challenges (Teise & Le Roux, 2016; Amnesty International, 2020). EE themes in policy documents like CAPS represent progress, but real classroom practices remain constrained by sustainability-illiterate leadership and the tightly controlled ATP (Basson, 2023).

These realities underscore the need for context-specific strategies and targeted professional development to operationalise ESD effectively within mathematics education.

## **2.2.2 Information and Communication Technology (ICT) in Mathematics**

This subsection explores the role of Information and Communication Technology (ICT) in mathematics teaching, focusing on available tools, resources, and integration strategies. It considers how ICT supports innovative teaching practices and its potential to facilitate the integration of ESD principles. This discussion frames ICT as a critical enabler in transforming mathematics classrooms for sustainability-oriented education.

### **2.2.2.1 ICT Tools and Resources for Mathematics Teaching**

In the digital age, integrating Information and Communication Technology (ICT) into mathematics education is increasingly essential for fostering learner engagement, supporting conceptual understanding, and preparing students for a technology-driven society. Globally, ICT tools such as Dynamic Geometry Software (DGS), Learning Management Systems (LMS), and mobile technologies have transformed how mathematics is taught and learned. However, in South Africa, ICT integration remains uneven due to systemic challenges such as infrastructural gaps, teacher preparedness, and socioeconomic disparities (Netsianda & Ramaila, 2021; Umugiraneza et al., 2018). This section explores ICT tools and resources in mathematics teaching, drawing on international studies and connecting their findings to the South African context to highlight opportunities and barriers to ICT-supported ESD integration.

#### **2.2.2.1 International Perspectives on ICT Tools in Mathematics**

Globally, ICT tools have been widely adopted in mathematics education. For example, in Nepal, Moodle was identified as a commonly used free Learning Management System (LMS) incorporating workshops, chat, comment boxes, and wikis to support peer assessment and collaboration (Dahal et al., 2020). In Indonesia, secondary school mathematics teachers reported using DGS for exploring geometric properties, GeoGebra for visualizing concepts, and CAS for symbolic calculations in algebra and calculus (Mailizar & Fan, 2020). However, the same study revealed that many teachers lacked sufficient knowledge of these tools.

In Ukraine, LearningApps and GeoGebra were found effective for inclusive education among students with special needs, enabling teachers to tailor activities to diverse learners

(Kramarenko et al., 2021). Similarly, studies in China and India identified factors such as limited technical skills, lack of planning time, and poor ICT infrastructure as key barriers to integration (Msafiri et al., 2023; Das, 2019).

#### **2.2.2.2 ICT Integration in South Africa: Contextual Realities**

In South Africa, studies reflect similar challenges and emerging practices. Netsianda and Ramaila (2021) found that teachers in Limpopo primarily use basic ICT tools such as Word processors, Excel spreadsheets, and Google Search, with limited exposure to advanced applications like GeoGebra. Graham et al. (2020) noted that even when resources and technical support are available, teachers may not prioritize ICT integration due to confidence issues and time constraints.

KwaZulu-Natal schools showed low levels of technology use, with calculators (33 out of 75 schools) and computers (21 out of 75 schools) being the most common tools (Umugiraneza et al., 2018). During the COVID-19 pandemic, teachers and students increasingly relied on tools like WhatsApp and Zoom for communication and collaboration, highlighting both the potential and limitations of mobile technologies (Naidoo, 2022; Mangundu et al., 2025).

#### **2.2.2.3 Barriers to ICT-Supported ESD Integration**

Several South African studies highlight contextual barriers to effective ICT integration:

- **Infrastructure and Access:** Over 50% of learners attend schools without any ICT infrastructure, and 90% lack ICT-equipped classrooms (Graham et al., 2024). Theft and vandalism of ICT assets further undermine integration efforts (Chisango & Marongwe, 2021; Mangundu et al., 2025).
- **Teacher Confidence and Training:** Teachers' lack of professional competence and confidence in using ICT tools often hinders integration (Zulu & Mudaly, 2023; Bećirović, 2023).
- **Socioeconomic and Security Concerns:** Township schools face high theft rates, internet instability, and frequent power outages (Zulu & Mudaly, 2023; Avci, 2022).

Despite these challenges, initiatives in Gauteng have provided some township schools with technology resources, though issues such as data costs and load-shedding persist (Musasa et al., 2025).

#### **2.2.2.4 Opportunities for ICT Integration in Mathematics**

Emerging innovations demonstrate ICT's potential to support ESD in mathematics. Smartphones have been used informally to provide access to online materials and quizzes, even in low-resource environments (Fernandez & Fernandez, 2021; Ngesi et al., 2018). While mobile technologies are officially restricted in schools, both teachers and learners are finding creative ways to leverage them for enhanced engagement and learning.

South African teachers have also expressed a growing interest in incorporating technology into their classrooms, with 80% showing willingness to adopt ICT in the future if given adequate support (Graham et al., 2024).

#### **2.2.2.2 Strategies for ICT Integration in ESD**

Regional and national policies provide a supportive context for ESD integration. A notable example is the Southern African Development Community (SADC) ESD Strategic Framework 2022–2030, which reaffirms education as a “common good” and a transformative tool for quality education (SADC, 2022). This framework advocates for the alignment of education policies and curricula with the Sustainable Development Goals (SDGs) across SADC countries, including South Africa. Moreover, one of the objectives of the strategic framework for ESD in the SADC is to connect ESD with 21st-century skills and to strengthen digitalisation skills and capacity in ICT for ESD (SADC, 2022). While this calls for an environment conducive to ESD integration through ICT, it is not clear how this could be achieved within individual subjects like mathematics. Furthermore, it is not clear how these policies are translated into teachers' Annual Teaching Plans.

To operationalise SADC's high-level objectives within mathematics classrooms, educators can develop contextually relevant strategies that integrate ESD themes into core mathematical concepts. For instance, lessons on statistics could involve analysing local water consumption or energy usage data in peri-urban communities, allowing students to

visualise and interpret patterns related to sustainability challenges. Algebra lessons might include modelling carbon emissions trends using linear and quadratic functions, helping learners to predict future outcomes and propose mitigation strategies. Geometry lessons could incorporate mapping and land-use planning problems that encourage learners to explore sustainable urban development. These examples not only promote critical thinking and problem-solving but also align with SADC's vision of embedding sustainability within subject-specific curricula.

ICT tools such as GeoGebra, dynamic graphing software, and spreadsheet applications like Excel can support these approaches by enabling students to interact with real datasets and visualise mathematical relationships dynamically. Teachers might also use collaborative platforms like Google Classroom or Padlet to facilitate discussions on sustainability issues, thereby encouraging participatory learning and reflective practices.

The integration of Indigenous Knowledge Systems (IKS) provides an additional layer of cultural relevance. Gula and Jojo (2024) demonstrated how rural South African mathematics teachers successfully incorporated indigenous artefacts such as isigubu (a drum), imoto yocingo (wire toy car), and ingolovane (wooden toy) to teach geometric principles. These artefacts made lessons more relatable, fostering greater learner engagement and improved conceptual understanding. For example, in a classroom of 96 grade 6 students, a teacher used the circular roof of a round hut as a model for teaching geometry, which not only sparked students' interest but also facilitated meaningful connections between mathematical concepts and their lived experiences. This highlights the potential of combining local cultural practices with digital media, such as using mobile phones or tablets to document community structures and analyse their geometric properties in class. By digitising these examples, teachers can preserve and share them across schools, further advancing SADC's objective of strengthening ICT capacity for ESD.

Mathematical modelling offers another promising avenue for integrating ESD through ICT. Bulut and Borromeo Ferri (2025) found that sustainability-themed modelling tasks enhanced pre-service teachers' abilities to connect mathematical ideas to real-world problems, such as waste management and population growth. South African mathematics

educators could adapt this strategy by designing tasks where learners use ICT tools to model local rainfall patterns or renewable energy outputs, encouraging discussions on water conservation and sustainable energy use. Such activities equip students with the analytical skills necessary for sustainable decision-making.

Jeong and González-Gómez (2024) emphasised the importance of dynamic, ICT-supported pedagogies (such as gamification, blended learning, and virtual labs) for making mathematics education more engaging and relevant to sustainability. However, they also cautioned that schools in under-resourced areas face significant challenges in adopting these approaches due to infrastructural and funding constraints. Zhang et al. (2020) proposed e-learning programmes as a potential solution, suggesting that online platforms can support ESD integration even in contexts where traditional ICT infrastructure is lacking.

Naidoo (2022) and Perienen (2020) also underscored the critical role of professional development and access to ICT resources in enabling teachers to integrate technology meaningfully. While teachers in Perienen's (2020) study recognised ICT's potential to enhance teaching, only a small percentage reported using it regularly due to inadequate training and limited access to resources. Similarly, Naidoo and Reddy (2023) argued that technology-enhanced teaching is essential for equipping learners with problem-solving and analytical skills necessary for sustainable development, particularly in the context of the Fourth Industrial Revolution (4IR).

At the tertiary level, Mhlabathi and Achieng (2024) highlighted how integrating digital tools into teaching and learning activities can advance ESD outcomes by enhancing students' competencies and making learning more applied to real-world sustainability challenges. However, they also acknowledged the persistence of a digital divide that limits the scalability of these innovations in under-resourced contexts.

Finally, Boonmoh et al. (2021) found that Thai secondary school teachers were aware of various technological tools and expressed willingness to integrate them into their classrooms. However, their efforts were constrained by a lack of ICT facilities, limited

administrative support, and rigid curricula. This reflects a broader trend across developing contexts, including South Africa, where the absence of systemic support structures severely limits teachers' capacity to harness ICT for ESD.

Thus, while frameworks like SADC's provide crucial policy direction, the successful integration of ESD through ICT in mathematics education depends on practical strategies, equitable access to resources, and robust institutional commitment. Without these, even the most innovative pedagogies and motivated teachers will struggle to realise the transformative potential of ESD in their classrooms.

### **2.2.3.3 Impact of ICT Integration**

Technology in education plays a transformative role. It bridges learning gaps and empowers marginalised learners by creating inclusive educational environments (Shudueva, 2023). In particular, ICT has been shown to position learners, especially those from disadvantaged backgrounds, to fulfil their roles in society and address immediate sustainability challenges. Fostering a culture of sustainability through ICT can cultivate critical awareness and active participation in global and local sustainability efforts (Meylani, 2025).

Msafiri and colleagues (2023) explored ICT's benefits in secondary school teaching and learning, highlighting how teachers use technology to design interactive lessons that actively engage learners. For example, they found that simulation software for modelling environmental scenarios enabled students to visualise resource depletion and explore alternative solutions. This approach strengthened mathematical reasoning and fostered critical thinking about sustainable practices, such as water conservation and renewable energy usage. These findings suggest that ICT tools provide mathematics learners with opportunities to apply abstract concepts to real-world sustainability issues.

Similarly, Angelaki et al. (2024) reported that in Greece, integrating sustainability and green informatics into ICT curricula encouraged students to collaborate on projects such as tracking their school's energy consumption using spreadsheet software. They then proposed cost-saving, eco-friendly alternatives. These projects enhanced learners' digital

literacy and instilled a sense of agency in addressing environmental challenges. Although this example comes from Europe, it offers valuable insights for South Africa, where similar tools could help learners in peri-urban schools explore local sustainability concerns, such as electricity shortages or water scarcity, within mathematics lessons.

Meylani's (2025) literature review showed that ICT-enabled mathematics classrooms promote dynamic learning environments. Learners collaborate to tackle complex, real-world problems. For example, dynamic graphing software allowed students to model population growth and predict its impact on resource use, sparking discussions about equitable distribution and environmental responsibility. These insights align with South Africa's Curriculum and Assessment Policy Statement (CAPS), which calls for teaching approaches that foster critical thinking and active citizenship. Unlike global overviews, the current study focuses on peri-urban schools in South Africa, where teachers' lived experiences reveal additional infrastructural and socio-economic constraints that influence ICT integration for ESD.

Karmova (2023) emphasised the importance of digital storytelling as a tool for embedding sustainability principles in education. For example, students in her study created digital narratives linking mathematical statistics to local issues such as deforestation and waste management. This helped them connect classroom concepts to pressing environmental challenges. In the South African context, this approach could assist mathematics learners in visualising the impact of plastic pollution in their communities and proposing sustainable waste solutions using data analysis techniques.

In Africa, Akintolu and Uleanya (2021) investigated adult education programmes in Nigeria that integrate ICT for SDG awareness. They observed that ICT enhanced participants' engagement and developed their problem-solving skills to address local environmental issues. This finding is particularly relevant for South African mathematics education because ICT integration could empower secondary school learners to apply their mathematical knowledge to local sustainability challenges.

While international studies offer critical insights into ICT's potential, their findings must be contextualised within South Africa's unique challenges and opportunities. Peri-urban schools often face infrastructural barriers, such as intermittent electricity and limited internet access. However, these constraints create opportunities for innovative, low-tech solutions. For example, using mobile phones for data collection and analysis can support sustainability education even in resource-limited environments. Drawing lessons from global best practices while tailoring them to South Africa's educational realities is essential for realising ICT's transformative potential in fostering ESD awareness and practices in mathematics education.

### **2.2.3 Teachers and ICT-supported ESD**

This subsection reviews literature on teachers' awareness, perspectives, and practices regarding ICT-supported ESD integration. It discusses professional development initiatives and systemic support mechanisms that influence teachers' ability to effectively implement sustainability education. This section is crucial for understanding the human and institutional factors that enable or constrain ESD integration through ICT.

#### **2.2.3.1 Teacher Awareness and Perspectives**

Teacher Education for Sustainable Development (TESD) is a specialised approach in teacher training that equips educators with the skills to help students tackle worldwide socio-environmental issues (Fischer et al., 2022). This approach encompasses policies, practices, and research aimed at incorporating ESD-related concepts and goals into teacher education (Fischer et al., 2022). This type of education has the potential to spread awareness about ESD and sustainability. In their study, Fischer and his fellow researchers (2022) undertook a systematic literature review of 158 peer-reviewed publications. Their exploration revealed that there is a growing interest in TESP. Of the 158 journal articles, 146 focused on pre-service teachers while 29 focused on service teachers. This indicates a strong focus on pre-service teachers as opposed to service teachers who are currently on the ground. This underscores a need to investigate ESD integration into mathematics by service teachers, which calls for an understanding of their level of awareness of ESD. It is

more likely that pre-service teachers are aware of ESD compared to service teachers, given the strong focus on pre-service teachers.

Pedagogical Content Knowledge (PCK) is defined as knowledge that is developed over time by the teacher (Gess-Newsome, 2015). It has been reported by several studies that PCK has an impact on student learning (Abukari et al., 2022, Usak et al., 2022; Gess-Newsome et al., 2019; Keller et al., 2017). Therefore, if there is no effort to educate mathematics teachers on ESD, it is less likely that they will develop the PCK required to facilitate transformation as demanded by the environment, society and economy.

In a recent study, which explored how Swedish upper secondary science teachers modify their teaching of the environmental aspects of sustainable development to suit the various vocational education programmes in which their students are enrolled, teachers expressed different views about making changes to their teaching (Forsler et al., 2024). Some teachers were worried that adjusting their teaching too much to specific vocational programmes might result in students missing key science content that is universally relevant; some expressed that they had limited time to tailor lessons for each vocational track, especially if they were responsible for multiple programmes; some teachers found that students were more interested and engaged when sustainability topics were directly linked to their future careers; some believed that connecting sustainability to students' future jobs would help them realise their potential impact on sustainability practices; and some science teachers collaborated with vocational teachers to create integrated lessons that aligned with both sustainability concepts and practical vocational skills. Even though this is a Swedish study focused on science, it confirms that in some parts of the world, teachers are aware of ESD and ESD is already integrated into educational settings. This study also provides lessons on potential challenges that could arise when promoting ESD integration into mathematics.

In another study, which examined how teachers perceive, understand, and implement ESD in their classrooms, teachers' knowledge of sustainable development, ESD and ESD programmes was assessed. A significant 79.7% of teachers revealed that they have never heard of such, with 12.4% having considerably limited knowledge, 4.4% with basic knowledge, and 3.4% with thorough understanding (Waltner et al., 2020, p. 1). These

figures suggest that Professional Development is needed to spread awareness about ESD and sustainability in general. However, the study also revealed that interest in SDGs has increased from 2007 to 2019. With growing interest, teachers may be more willing to incorporate the SDGs into their lesson plans which could lead to more interdisciplinary teaching, connecting sustainability with subjects such as science, social studies, and economics. Waltner et al. (2020) also established that teachers are not interested in abstract policies, they want actionable support that speaks to both teaching and school objectives. This finding suggests that teachers are already aware of sustainability concepts but struggle to effectively implement them in their classrooms. Therefore, instead of broad, theoretical ESD policies, teachers need clear, subject-specific strategies and materials that align with their curricula.

Even though the Waltner et al. study (2020) was undertaken in a German secondary school setting, its findings are highly relevant to teacher awareness of ESD in the South African context. The study provides insights into how teachers perceive ESD (e.g. teachers do not need more abstract policies but rather concrete teaching support), their level of awareness, and the challenges they face in implementing it in their classrooms. These insights could also apply to the South African education system where sustainability is recognised as important but often not fully integrated into teaching practices (Teise & Le Roux, 2016).

Goller and Markert (2024) recently analysed teacher educators' perceptions, understanding, and beliefs about ESD in higher education and found that interest in ESD and the SDGs has increased over time, showing that teachers are becoming more engaged with sustainability issues. This increase in interest may suggest a shift in mindset towards recognising sustainability as a key part of education.

Goller and Markert (2024) also confirmed that, while there is literature on how teachers perceive ESD (which is usually based on literature reviews), these studies rarely focus on teachers' lived experiences, which is key to ESD integration. Since most studies on teachers' perceptions of ESD are literature-based rather than experience-based, they may not fully capture how teachers truly engage with sustainability concepts in practice. Therefore, without studies exploring teachers' actual experiences, challenges, and

successes, it is difficult to assess whether their awareness of ESD translates into meaningful classroom integration. The findings of the Goller and Markert study are also relevant in terms of the South African context, where ESD is included in education policies (CAPS, 2011), and various sustainability initiatives exist. However, without studies that explore teachers' actual experiences, challenges, and successes in implementing ESD, it may be difficult to determine how awareness of sustainability concepts translates into classroom practice. Understanding teachers' lived experiences could provide insights into the factors that support or hinder ESD integration within the South African education system.

In a national case study that explored the knowledge, attitudes, and challenges of South African teachers in integrating ESD into their teaching, it was established that poor understanding of sustainable development still exists in South African schools and that teachers do not have the capacity to integrate sustainability issues into teaching (Lotz-Sisitka, 2011). Prior to Lotz-Sisitka's study, several large-scale national studies were undertaken by the biodiversity sector (HSRC, 2010), the Department of Environmental Affairs (DEA, 2010), and the Department of Science and Technology's Global Change Grand Challenge National Research Plan (DST, 2010) to explore the skills development issues pertaining to sustainable development pathways. More recent studies confirm that these challenges persist. For instance, Singh-Pillay (2023) highlights that pre-service teachers often lack hands-on, transformative experiences necessary for ESD integration. Similarly, Munasi (2024) finds that despite supportive policy frameworks, South African teachers encounter systemic and resource barriers when embedding ESD in practice. Olawumi and Mavuso (2024) further argue that in-service teacher training programmes remain underfunded and fragmented, limiting capacity building. Moreover, a growing body of research points to the potential of online platforms to deliver ESD-focused professional development, though their effectiveness hinges on thoughtful pedagogical design (Staden et al., 2023). These studies all pointed to the fact that teachers need Professional Development and pedagogical content knowledge on sustainability. These studies confirm that teachers in South Africa are generally not fully aware of sustainability and how its integration looks like in the education setting. If Professional Development on ESD is not

prioritised, awareness among teachers may remain at policy level rather than being translated into daily classroom practice.

In South Africa, teachers are recognised as critical in a mission to integrate ESD into education (Olawumi & Mavuso, 2024). However, Lotz-Sisitka (2011) and various other researchers have reported that teachers do not have the capacity to integrate ESD, which is attributed to gaps in their pre-service training and insufficient Professional Development opportunities targeted at ESD integration (Imara & Altinay, 2021). Similarly, Olawumi and Mavuso (2024) observed that many teachers face challenges in integrating environmental education effectively because they lack sufficient content knowledge and pedagogical understanding of climate change and sustainable development. These sentiments underscore that teachers (both pre-service and in-service) are generally unaware of ESD in South Africa and, as a result, are not in a position to integrate it into their teaching practices. The implications of limited ESD awareness for mathematics instruction are significant. Teachers who lack conceptual understanding of sustainability are unlikely to design lessons that connect mathematics to real-world issues such as resource management, financial literacy, and environmental conservation (Basson, 2023). Systematic reviews affirm that while mathematics offers a powerful context for ESD, teachers often resist integration due to limited knowledge and resistance to change, highlighting the need for professional development that includes concrete, example-rich approaches (Vásquez et al., 2023). Further, Su et al. (2023) emphasize that effective ESD teacher training must develop ecological and mediational competencies, mathematical content knowledge, and pedagogical strategies that explicitly link mathematics and sustainability. Without this tailored PD, mathematics instruction may remain abstract and exam-focused, missing opportunities to nurture critical thinking and problem-solving aligned with ESD principles. Effective Professional Development programmes must therefore be designed to equip teachers with both sustainability knowledge and subject-specific pedagogical tools. While awareness of ESD among teachers is a critical first step, their perspectives on sustainability concepts and the realities of classroom practice reveal deeper insights into the barriers and enablers of integration. Understanding these perspectives is essential to contextualize how awareness (or lack thereof) translates into teaching practices.

Waltner et al. (2020) assessed secondary school teachers' knowledge, attitudes, and implementation practices regarding Education for Sustainable Development (ESD) in Baden-Württemberg, Germany. This study revealed that teachers are not overly concerned with abstract policies informing ESD; rather, they prioritise concrete, actionable support relevant to their teaching contexts and schools' objectives (Waltner et al., 2020). This underscores the importance of engaging teachers in critical discussions about their professional realities and designing effective Professional Development programmes that directly respond to these realities. PD initiatives informed by teachers' perspectives are more likely to equip educators with practical tools and confidence for integrating ICT in ESD meaningfully.

Othman et al. (2024) explored barriers at teacher, school, and system levels that influence motivation to integrate ICT for SDGs. Their large-scale survey of 1,253 Malaysian teachers revealed that factors such as teachers' ICT skills, beliefs, curriculum demands, and infrastructure significantly shape whether they adopt ICT for ESD. Importantly, these findings suggest that PD programmes need to move beyond a one-size-fits-all approach and provide targeted support that builds teachers' technical confidence, enhances their conceptual understanding of sustainability, and helps them navigate contextual constraints such as curriculum rigidity and exam pressures.

Similarly, Kiapene (2022) identified key drivers motivating ICT use in mathematics classrooms, including the push to modernise pedagogy, school/national policies, and ICT's potential to make teaching large classes more manageable. Yet, teachers also reported limitations such as inadequate ICT infrastructure, insufficient management support, and lack of training. These insights highlight the need for PD programmes to not only focus on technical ICT skills but also on developing strategies for overcoming contextual barriers (e.g., using low-bandwidth tools, integrating ICT into large-group teaching).

In Namibia, Kanandjebo (2024) reported that pre-service mathematics teachers were aware of sustainability's importance but felt underprepared to design lessons integrating ESD themes due to a lack of examples and pedagogical strategies. This reinforces the argument for embedding ESD-specific ICT training into pre-service PD programmes, ensuring future

teachers gain exposure to practical tools, lesson exemplars, and culturally relevant approaches for integrating sustainability.

Anyolo et al. (2018) and Munasi (2024) highlighted how even when teachers understand ESD's importance, ICT infrastructure gaps and insufficient training remain significant barriers. Notably, Munasi (2024) found that teachers who used visual ICT resources like slides and videos in Life Sciences lessons made abstract sustainability concepts more accessible for learners. This suggests that PD programmes should emphasise practical applications of ICT for explaining abstract ESD themes in mathematics, such as using digital simulations for climate modelling or interactive platforms for exploring resource management data.

Teachers' deeply held beliefs also shape ICT integration. Gula and Jojo (2024) reported that teachers who linked mathematics to culturally familiar examples (e.g., rain harvesting measurements for teaching ratio) noted higher student engagement and improved understanding. Likewise, Sackstein et al. (2022) and Ramnarain et al. (2023) found that teachers with strong intrinsic beliefs about technology's value were more likely to use ICT transformatively, regardless of external constraints. These findings stress that PD efforts must go beyond technical skills training to address teachers' pedagogical beliefs and attitudes, fostering mindsets that embrace ICT as a vehicle for promoting ESD.

Basson (2023) underscored inequities between public and private schools regarding ICT for ESD. Teachers in well-resourced private schools were able to integrate ICT into collaborative, problem-solving activities, while public school teachers cited barriers such as lack of equipment and minimal institutional support. PD programmes informed by these realities should focus on equity-sensitive strategies, such as training teachers in low-tech solutions and advocating for school-level policies that enable ICT access for ESD.

Collectively, these studies highlight that understanding teachers' perspectives is critical for designing professional development initiatives that are contextually grounded, responsive, and practical. Targeted PD programmes informed by these insights should:

- Build teachers' technical and pedagogical capacity for ICT integration.

- Provide subject-specific exemplars for embedding ESD into mathematics lessons.
- Support teachers in developing adaptive strategies for overcoming resource constraints.
- Engage teachers in reflective practices to challenge limiting beliefs and promote transformative use of ICT for sustainability education.

Thus, the insights from these studies not only map the challenges teachers face but also offer valuable directions for developing PD frameworks that empower educators to integrate ICT in ways that align with ESD's transformative goals.

### **2.2.3.2 Professional Development for ICT and ESD**

While technology supports critical thinking, problem-solving, conceptual understanding and retention, its successful implementation in education depends on robust Professional Development (PD), reliable infrastructure, and strategies for overcoming resistance to change and disparities between urban and rural areas (Meylani, 2025). Across diverse contexts, research has emphasised that without carefully designed PD initiatives, integrating Education for Sustainable Development (ESD) and Information and Communication Technology (ICT) into mathematics education remains limited.

Parry and Metzger (2023) identified inadequate PD for both pre-service and in-service teachers as a major barrier to effective ESD integration. Their reflections on the experiences of a British science teacher reveal that even in developed contexts, gaps in PD contribute to teachers' struggles with implementing sustainability-related content. This issue is particularly acute in South Africa's peri-urban areas, where limited resources and systemic inequities exacerbate challenges related to ICT and ESD integration.

Meylani (2025) also highlighted the complexity of PD needs, identifying key barriers such as limited technological accessibility, insufficient infrastructure, and the challenge of adapting pedagogical practices to incorporate ICT effectively. These barriers can be grouped into three categories. First, institutional barriers include poorly designed school policies that fail to prioritise teacher training and support, along with curriculum rigidity that limits opportunities for integrating innovative approaches. Second, infrastructural

barriers refer to the scarcity of reliable internet, devices, and technical support. Third, personal barriers encompass teachers' limited ICT skills, low confidence, and resistance to adopting new pedagogies. These categories highlight the multifaceted nature of challenges that PD programmes must address if they are to support teachers effectively.

Several studies have suggested targeted strategies for overcoming these challenges. Olawumi and Mavuso (2024) argued that continuing PD for in-service teachers plays a critical role in equipping educators with the skills necessary for integrating ESD meaningfully into their teaching. This aligns with findings by Bascopé et al. (2019), who observed that PD programmes with clear guidelines and practical resources enabled teachers in Chile and Germany to integrate sustainability principles into classroom instruction more effectively.

Yue and Ji (2020) stressed that teachers' PD must prepare them to navigate 21st-century demands in technology, economy, and politics, implying a need for ICT competencies as foundational skills. Similarly, Li and Tsai (2022) highlighted a disconnect between sustainability frameworks and classroom practices, suggesting that PD programmes must address this gap by providing teachers with concrete examples and tools for implementation.

The South African experience further illustrates these challenges. The Fundisa for Change teacher professional development (TPD) course exposed participants to learner-centred pedagogies and ESD-related content. However, Thenga et al. (2020) reported that its overall impact on transforming classroom practices was limited, with only one in five teachers varying their teaching approaches after attending the programme. This suggests that one-off interventions are insufficient. Instead, PD programmes should include ongoing support mechanisms such as collaborative reflection sessions, peer mentoring, and follow-up workshops to embed practices sustainably.

Barriers to ICT integration for ESD in mathematics are also well-documented. For example, Basson (2023) found that educators often lacked qualifications related to ESD, making them hesitant to teach content they felt unprepared for. Similar findings were

reported by Tang et al. (2023), Yuan et al. (2023), and Zulu and Mudaly (2023), who identified teachers' lack of confidence in using ICT tools as a significant obstacle. Mangundu et al. (2025) further observed that while schools received donations of ICT resources such as devices and data bundles from organisations like Eskom, these were often underutilised due to insufficient ongoing support and training for teachers.

This underutilisation underscores the importance of ICT-focused PD programmes that equip teachers with both technical skills and pedagogical strategies. Chisango and Marongwe (2021) reported that when teachers lacked ICT proficiency, they were unlikely to experiment with or adopt digital approaches in their lessons. Hence, PD initiatives must simultaneously build confidence, challenge teachers' beliefs about technology, and provide practical examples of integrating ESD themes into mathematics.

While the literature affirms the value of PD, there is still limited research on programmes specifically designed to support the integration of ESD through ICT in mathematics education. Most studies either focus on teacher training for ESD in mathematics or ICT integration in mathematics but rarely explore the intersection of these two critical areas. This gap highlights an urgent need for holistic PD frameworks that address institutional, infrastructural, and personal barriers comprehensively. Such frameworks should be context-sensitive, particularly for peri-urban and rural South African schools, where systemic inequalities pose significant constraints on ICT and ESD integration.

#### **2.2.3.2.1 Global Insights on PD Models for ESD-ICT Integration**

While systemic barriers have limited the effective integration of ESD and ICT in South African teacher Professional Development, lessons can be drawn from successful models implemented in other contexts. These models provide practical pathways and design considerations for scalable, context-sensitive, and transformative Professional Development that can inform future initiatives in South Africa.

A compelling example from Malawi emphasizes the importance of co-learning between teacher educators and student teachers as a foundation for technology professional development. Gondwe (2021) found that student teachers' perspectives on their educators'

use of technology revealed crucial insights that supported more relevant and collaborative Professional Development. This approach suggests that student-teacher feedback and peer dialogue can help redefine teacher educator competencies and foster meaningful change in ICT integration (Gondwe, 2021).

In Mongolia, a case study demonstrated the integration of ESD concepts into ICT-based assignments in secondary education. Lkhagvasuren (2022) illustrated how embedding sustainability themes into everyday digital tasks significantly raised students' environmental awareness while enhancing their digital literacy. This model shows how ICT tools can be leveraged not only for skill development but also for instilling sustainability values in learners (Lkhagvasuren, 2022).

The Rivers2Lake program in the United States stands out as a comprehensive transformational Professional Development initiative for ESD. Based on UNESCO's learning processes, this program emphasized participatory learning, systems thinking, and collaboration among educators, scientists, and Indigenous communities. Ernst et al. (2020) reported sustained shifts in teacher practices and student engagement through a year-long support model that included immersive field experiences and mentorship. Such a model demonstrates the value of continuous engagement, cross-sectoral collaboration, and localized learning, offering a template for contextual adaptation in South Africa (Ernst et al., 2020).

Switzerland provides an effective example of ICT-focused Professional Development through an adapted cascade model. El-Hamamsy et al. (2024) describe how active regional teachers were trained by experts and then mentored throughout the implementation of a digital education Professional Development program. Unlike traditional cascade models prone to dilution and disengagement, this model ensured alignment, contextual relevance, and ongoing expert support, leading to outcomes comparable to expert-led training. This approach could guide the design of ICT PD in South Africa, especially in resource-constrained regions (Hamamsy et al., 2024).

A global systematic review by Hennessy et al. (2022) highlighted various promising modalities for technology-mediated Teacher Professional development in low- and middle-income countries, including blended learning, virtual coaching, and video-stimulated reflection. The study emphasized the central role of peer facilitators and context-specific adaptation, cautioning against one-size-fits-all solutions. These findings reinforce the need for flexible, technology-enabled PD designs in South Africa that center teacher agency and local relevance (Hennessy et al., 2022).

Another model, the Tutorials, Instructional Modelling, and Support (TIMS) approach from the United States, offers practical insight into structuring ICT Professional Development. Luo et al. (2022) demonstrated how teachers benefited from sequential phases of tutorials, instructional modelling, and ongoing support. This structure promoted hands-on learning, contextual relevance, and collaborative reflection, effectively changing teachers' attitudes and classroom practices. The TIMS approach could inspire similarly structured Professional Development programs within South African schools (Luo et al., 2022).

While these international models differ in scale and context, common threads emerge collaborative learning, contextual adaptation, sustained support, and integration of ESD and ICT into authentic teaching practice. For South Africa, these elements suggest that future Professional Development initiatives should move beyond short-term workshops towards long-term, participatory, and curriculum-integrated models that leverage local environmental contexts and digital tools.

#### **2.2.4 Summary and Implications**

Literature suggests that there is no universal definition of ESD. Defining ESD requires the consideration of one's context. In the South African context, ESD is characterised as being holistic and integrated; value-driven; comprised of critical thinking; geared towards problem-solving and action; multi-methodological; and participatory (Teise & Le Roux, 2016). This implies that teaching and learning should reflect these characteristics. While ESD is considered an integral part of achieving all Sustainable Development Goals, sub-Saharan Africa is confronted with a variety of contextual challenges that hinder ESD integration. These challenges include inconsistent policy and funding priorities, restricted

access and inclusion, gender inequality, physical limitations, curriculum limitations, and insufficient teacher training.

ESD is somewhat evident in the South African education framework. However, there seems to be a lack of evidence in actual classroom practice. It is unclear how this integration should occur during teaching and learning. The CAPS document implies the infusion of sustainable development into mathematics yet does not explicitly state how this should be articulated in the classroom. Globally, teachers highlighted the need for effective Professional Development to integrate ESD. ICT is proving to have a significant impact on the overall educational experience. This implies that ESD integration could also gain momentum through the use of ICT. However, this component requires teachers to have certain ICT competencies in order to harness its true value. This calls for Professional Development to capacitate teachers in this regard. Furthermore, schools would need to be ICT ready for teachers to enhance their teaching and learning through ICT. This is a challenge in Africa with its very limited ICT infrastructure and more so in the less developed schooling contexts.

What was notable from the literature is that South African education policies (like CAPS) demonstrate intent to integrate sustainability concepts into mathematics. However, the implementation of this is not clear. There is less emphasis on the use of ICT to promote ESD integration into mathematics education. The studies clearly tend to focus on ESD integration (Basson, 2023; Bascopé et al., 2019; Munasi, 2024; Parry & Metzger, 2023) or ICT integration (Meylani, 2025; Tang et al., 2023; Yue & Ji, 2020; Zulu & Mudaly, 2023) while not much has been written about ESD integration facilitated through ICT in mathematics teaching. Therefore, this study aimed to explore the use of ICT to facilitate ESD integration in mathematics education. In the next section, the theoretical frameworks that underpin this study will be discussed.

### **2.3. THEORETICAL FRAMEWORKS**

This study was informed by two theoretical frameworks to conceptualise the integration of ESD and Information and Communication Technology (ICT) in mathematics teaching. The

selected frameworks are Msafiri et al.'s (2023) ICT Integration Framework and Nerstrom's (2014) Transformative Learning Model. Together, these frameworks provide a comprehensive lens for understanding both the systemic factors and personal reflections that influence teachers' practices in integrating ICT for promoting sustainability.

### **2.3.1. ICT Integration Framework**

This framework has been rigorously developed through 51 peer-reviewed studies on the integration of ICT in education (Msafiri et al., 2023). The studies were reviewed in their paper range from 2008 to 2023. Msafiri's study focused on the impact of ICT in secondary schools. Similarly, the present study is also aimed at the use of ICT to promote ESD in mathematics teaching at secondary school level.

The ICT Integration Framework was developed by Msafiri et al. (2023) through a systematic literature review of 51 peer-reviewed studies published between 2008 and 2023. The framework emerged from the need to synthesise global insights on ICT adoption in secondary education and to identify critical factors for successful implementation. It is particularly relevant for resource-constrained contexts, such as peri-urban South African schools, where systemic and infrastructural challenges often hinder ICT adoption.

Figure 2.1 presents the ICT Integration Framework as a dynamic system comprising three interconnected components: Professional Development, ICT Integration, and Problem Identification. The arrows and feedback loops in the figure emphasise how these components support continuous improvement and adaptation in teaching practices.



*Figure 2.1: ICT Integration Framework adapted from Msafiri et al. (2023, p. 13)*

The framework has three main themes, namely Professional Development, ICT Integration, and Problem Identification. The various components interact with each other.

### ***Professional Development***

This component highlights the importance of equipping teachers with both technological and pedagogical skills in environments that are supported by school leadership, the Department of Education, and the broader community. Msafiri et al. (2023) observed that inadequate professional development remains a major barrier to effective ICT integration. For mathematics educators, professional development should include training on tools such as GeoGebra for visualising geometric concepts and spreadsheet software for analysing sustainability-related data sets.

### ***ICT Integration***

ICT Integration involves embedding technology into daily teaching and learning practices in ways that engage students and strengthen conceptual understanding. Msafiri et al. (2023)

emphasise that effective integration depends on factors such as alignment with curriculum objectives, teacher motivation, and access to functional ICT tools. In mathematics classrooms, digital simulations, virtual labs, and dynamic graphing software can enable learners to explore real-world sustainability challenges, such as modelling population growth or energy consumption.

### ***Problem Identification***

Problem Identification focuses on recognising barriers that teachers encounter when attempting to integrate ICT. These barriers may include institutional constraints, such as rigid curricula and unsupportive policies, infrastructural issues like unreliable electricity and insufficient ICT devices, and personal factors such as teachers' limited confidence or ICT literacy. This study utilised focus group discussions and classroom observations to uncover these challenges and inform the design of targeted professional development initiatives.

This framework aligns closely with the research questions of this study. Table 2.1 illustrates how each research question maps onto the framework's components and guided the structure of the investigation.

*Table 2.1: Alignment of Msafiri's ICT Integration Framework with the Research Questions*

<b>Msafiri's ICT Integration Framework Components</b>	<b>Research Question 1 (Level of awareness)</b>	<b>Research Question 2 (Utilisation of ICT tools)</b>	<b>Research Question 3 (Support for teachers)</b>
<b>Professional Development</b>	This component focuses on technological understanding, pedagogical knowledge and leadership support, with RQ1 providing insights to all these.	This component addresses how effectively teachers have been equipped with the skills to use ICT tools in their mathematics teaching. Therefore, RQ2 provided insights into the above.	This component emphasises the need for Professional Development, leadership support, and resource availability, directly related to understanding the extent of support provided to teachers.
<b>ICT Integration</b>	Teachers' awareness of and confidence in using ICT tools to incorporate ESD principles in mathematics can be evaluated through this component looking at curriculum alignment, skill development and motivation.	Directly aligns with understanding how teachers are integrating ICT into ESD-related mathematics instruction, focusing on the tools and strategies they employ.	Considers how school leadership and educational systems create an environment conducive to ICT use, indicating the level of institutional support.
<b>Problem Identification</b>	This component helps to identify gaps in awareness and challenges teachers face in understanding ICT's role in integrating ESD into mathematics.	This component provides a framework to assess obstacles that prevent teachers from effectively using ICT tools, such as technical or pedagogical challenges.	Through this component, the study can highlight the support required to address the identified challenges, ensuring teachers can effectively integrate ESD through ICT with adequate backing from leadership of the school.

Although the ICT Integration Framework provides a strong foundation for analysing systemic and technical factors, it does not directly address the personal cognitive and reflective processes that influence teacher transformation. To address this, Nerstrom's Transformative Learning Model was adopted as a complementary framework.

### 2.3.2. Nerstrom's Transformative Learning Model

The Transformative Learning Model was developed by Nerstrom (2014) to simplify Mezirow's original ten-phase model of transformative learning. Nerstrom reviewed over 500 studies and found that no visual representation existed to explain the complex processes of transformative learning. She condensed Mezirow's model into four sequential phases: Experience, Assumptions, Challenging Perspectives, and Transformative Learning. This streamlined model offers a practical way to understand how teachers reflect on and reconstruct their beliefs and practices.

Figure 2.2 depicts this cyclical process, highlighting how each phase builds on the previous one. The arrows in the figure emphasise that transformative learning is iterative and ongoing.



*Figure 2.2: Nerstrom's Transformative Learning Model (Nerstrom, 2014, p.328)*

### ***Experience***

This phase highlights the role of teachers' prior knowledge and lived experiences in shaping their teaching practices. According to Nerstrom (2014), experiences are shaped through interactions with others and the environment, providing the foundation for learning. In this study, participants brought years of mathematics teaching experience and shared their insights on ESD and ICT integration during initial focus group discussions.

### ***Assumptions***

This phase reflects how teachers develop assumptions based on prior experiences. These assumptions, which act as lenses through which teachers interpret new information, may include beliefs about the role of mathematics and its connection to sustainability. For example, some teachers assumed that ESD topics such as climate change and resource management fall outside the scope of mathematics, while others recognised the relevance of integrating these topics using ICT tools.

### ***Challenging Perspectives***

New experiences, particularly those introduced through professional development activities, can challenge deeply held assumptions. In this study, workshops exposing teachers to innovative ICT tools, such as Kahoot, ChatGPT, and GeoGebra, provided opportunities to reflect on and rethink traditional teaching approaches. Teachers were encouraged to explore alternative strategies for engaging students with real-world sustainability problems.

### ***Transformative Learning***

In this final phase, teachers adopt new perspectives and apply them in practice. For example, teachers redesigned lesson plans to include ICT-supported tasks that required learners to use mathematical concepts in analysing environmental data or modelling sustainable solutions. This transformation was evident during classroom observations and follow-up discussions where participants expressed intentions to sustain these practices and share them with colleagues.

Table 2.2 demonstrates how Nerstrom’s four phases align with Msafiri’s framework and complement its focus on systemic factors by emphasising teachers’ cognitive and reflective processes.

*Table 2.2: Alignment of Msafiri’s ICT Integration Framework and Nerstrom’s Transformative Learning Model*

<b>Msafiri’s ICT Integration Framework</b>	<b>Nerstrom’s Transformative Learning Model</b>	<b>Explanation of alignment</b>
Professional Development	Experience and Assumptions Phases	Professional Development focuses on teachers' prior knowledge and their assumptions about the role of technology and ESD in mathematics. Nerstrom’s model emphasises the importance of prior experiences and assumptions formed through interaction which aligns with the need for Professional Development in ICT.
ICT Integration	Challenge Perspectives Phase	As teachers integrate ICT, they face new experiences that challenge their existing pedagogical approaches, which mirrors Nerstrom’s phase where assumptions are challenged, leading to potential reflection and changes in perspective.
Problem Identification	Transformative Learning Phase	Problem identification aligns with Nerstrom’s final phase, where new perspectives are adopted and acted upon. Teachers identify find new ways of planning and teaching using ICT and reflect on the transformative process of adopting new teaching methods through ESD integration.

Together, Msafiri’s ICT Integration Framework and Nerstrom’s Transformative Learning Model provide complementary perspectives for analysing ICT-supported ESD integration in mathematics education. Msafiri’s framework highlights the structural and systemic factors that enable or hinder ICT adoption, while Nerstrom’s model captures the cognitive and experiential processes teachers undergo as they reflect on and refine their teaching practices. This dual-framework approach is particularly well-suited to exploring how

professional development can address both technical challenges and attitudinal barriers in peri-urban South African schools.

# Chapter 3 | Methodology

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## 3.1 INTRODUCTION

The integration of ESD and Information and Communication Technology (ICT) into mathematics education is considered critical in preparing learners for the challenges of the 21st century (Jeong & González-Gómez, 2024; Msafiri et al., 2023). Mathematics, as a foundational subject, provides opportunities for fostering critical thinking, problem-solving, and data literacy, which are skills that align with sustainability goals (Naidoo & Reddy, 2023; Bulut & Borromeo Ferri, 2025). When combined with ICT, mathematics teaching can offer innovative ways to engage learners with real-world issues such as climate change, resource management, and sustainable economic practices (Gula & Jojo, 2024; Mhlabathi & Achieng, 2024). This study addresses a gap in the literature by exploring how ESD can be embedded into mathematics teaching through ICT in peri-urban South African schools, providing insights that are contextually relevant (Basson, 2023).

Given the study's focus on understanding teachers' experiences and practices, qualitative methods were selected as the most appropriate approach. Focus group discussions, classroom observations, and post-observation interviews enabled the researcher to capture rich, in-depth data about teachers' perspectives and the contextual factors influencing their ability to integrate ESD through ICT. These methods align well with the study's objectives, as qualitative approaches are well suited for exploring the lived experiences and reflective practices of teachers within their unique school environments (Creswell, 2015; Adams et al., 2022).

There is global consensus on the importance of sustainable development, which gave birth to the United Nations' 17 Sustainable Development Goals (SDGs). ESD, under SDG 4, is key in achieving the other 16 goals, necessitating its integration into teaching, particularly in mathematics. At the same time, ICT is known for its ability to enhance teaching and learning, making it beneficial to merge ICT with ESD in mathematics education. However, while there is extensive literature on ESD and ICT integration separately, there is a lack of studies focusing on their combined application in

mathematics teaching. Consequently, this means teachers will need Professional Development to effectively integrate ESD through ICT in their mathematics lessons.

As a result, the primary purpose of this study was to explore the integration of ESD into mathematics teaching through ICT. This chapter presents and discusses the research methodology used for this study. According to Goundar (2012), research methodology refers to the procedures employed by researchers when explaining, describing and predicting a phenomenon. Research methodology is therefore a science of how the research is conducted and it serves as a systematic way of solving a problem (Goundar, 2012). Similarly, Verma et al. (2024) defined methodology as systematic and scientific means to solve a problem. For Bahishti (2022) Research methodology refers to the process of designing, conducting, and analysing research studies. It provides a structured approach to conducting research, ensures the reliability and validity of research findings, facilitates communication and collaboration, and helps to advance knowledge in a particular field.

This chapter commences by presenting Table 3.1 which shows the research questions linked to each objective, and the research methods, instruments and data analysis methods used. The chapter then discusses the research design, followed by the research paradigm, sampling strategy, data-generation methods, data analysis, and validity and reliability. Ethical considerations are also discussed.

*Table 3.1: Linking Research Questions, Instruments Method, Research Instrument and Analysis*

Research Question	Research Method	Research Instrument	Data Analysis Method
1. What is the level of awareness among mathematics teachers regarding the integration of ESD into mathematics instruction through the utilisation of ICT?	Focus Group Discussion (FGD)	• Focus Group Interview Schedule (Appendix A1)	Thematic Analysis
2. How do teachers in the Pinetown district utilise ICT tools to facilitate the integration of ESD principles into mathematics teaching practices?	• Focus Group Discussion (FGD) • Observation	• Focus Group Interview Schedule (Appendix A1)	Thematic Analysis

	<ul style="list-style-type: none"> <li>• Post-Observation Interviews</li> </ul>	<ul style="list-style-type: none"> <li>• Observation Schedule (Appendix 1B)</li> <li>• Post-Observation Interview</li> </ul>	
3. To what extent is support provided to teachers to facilitate the integration of ESD into mathematics teaching through ICT?	Focus Group Discussion (FGD)	<ul style="list-style-type: none"> <li>• Focus Group Interview Schedule (Appendix A1)</li> </ul>	Thematic Analysis

### 3.2 RESEARCH PARADIGM

A research paradigm can be defined as worldview, a school of thought, or a set of beliefs that underpins a researcher’s interpretation of the research data (Khatri, 2020). The paradigm determines how the research questions and objectives are to be explored. This study was informed by the interpretive paradigm. This worldview allowed the study to treat the context and its situation as unique while considering associated circumstances and the participants of the study (Alharahsheh & Pius, 2020). Interpretivist researchers are concerned with reality that is based on the subjective experiences of the external world as opposed to a permanent label of an object based on its repeatedly recorded behaviour (Kumatongo & Muzata, 2021). This assertion corresponds with the nature of case studies which aims to perform an in-depth examination of the phenomena. Multiple case study research is a qualitative method that compares individual cases, captures diverse perspectives, and provides deep insights into a broader phenomenon while preserving each case's uniqueness. (Adams et al., 2022). Furthermore, interpretivism tends to focus on the individuals together with their interpretation of the world around them (Ugwu et al., 2021). This study is concerned with understanding the subjective experiences of mathematics teachers in their context guided by the interpretive worldview principles.

### 3.3 RESEARCH DESIGN

Multiple case studies are considered qualitative methodologies that allow researchers to compare individual cases which creates depth and understanding of a

phenomenon under study (Adams et al., 2022). Qualitative research is concerned with obtaining a deeper understanding of a specific case together with depth exploration which ultimately results in quality responses throughout the research process (Creswell, 2015). Therefore, this study generated qualitative data from participants representing different cases (schools).

The decision for using multiple case study approach was also supported by the fact that evidence that emanates from multiple case studies is known to be reliable and strong and provides the writer an opportunity to clarify if the findings from the data are valuable or not (Quintão et al., 2020). Furthermore, multiple case studies tend to create more convincing theories and can provide vital works of literature that emanate from the differences and similarities of the different cases studied (Quintão et al., 2020). In general, case study research is characterized by an intensive analysis where a case could be a role, a person, a community, a group, or a country (Schoch, 2020).

This study aims to understand the integration of ESD into mathematics education through ICT where participants come from different schools with contextual differences, as such, the multiple case study is adopted. This study employed a systematic approach to gather in-depth knowledge from mathematics teachers' lived experiences. The study aimed to offer in-depth insights into the extent to which ESD is promoted through ICT. Given that participants of the study came from different schools; each school was treated as a different case.

### **3.4 SAMPLING STRATEGY**

Multiple Case Studies typically involves a small sample (a prevalent occurrence in qualitative research) where multiple cases over four are not realistically viable (Schoch, 2020). This study focused on the cases of three schools in the Pinetown district. This sample size is realistically manageable as it relates to Multiple Case Studies (Adams et al., 2022; Gustafsson, 2017).

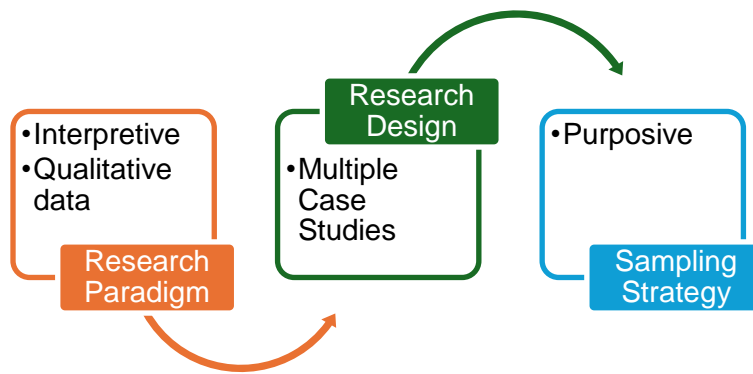
A purposive sampling technique ensures that the sample has characteristics that will serve the study (Andrade, 2021). Furthermore, purposive sampling is known to be effective when conducting Multiple Case Studies as this allows for an in-depth focus on a phenomenon (Bouncken et al., 2025). Therefore, all the participants in the study

had to be fully qualified mathematics teachers who are currently teaching mathematics at secondary school level. Furthermore, the selected schools had to follow the same curriculum regardless of their contextual differences. The purposive sampling was therefore homogeneous which is a common practice in studies that seek to understand the lived experiences of participants (Arslan & Dağhan, 2022). Moreover, Multiple Case Studies allowed the researcher to analyse data within each case (situation) and across different cases (situations). Hence, contextual differences are common in Multiple Case Studies.

The selected sample directly aligns with the study's objectives, which focus on exploring teachers' lived experiences and perspectives regarding ESD integration through ICT. Purposefully selecting mathematics teachers currently teaching in the Further Education and Training (FET) phase ensured that participants had direct relevance to the research focus. By working with schools that follow the same curriculum but have different contextual realities (e.g., rural and township settings), the study was able to capture diverse insights while maintaining comparability across cases.

While the sample size was limited to eight participants from three schools, this is typical for qualitative multiple case study research, which prioritises depth over breadth (Schoch, 2020; Adams et al., 2022). The findings are not intended to be statistically generalisable but are transferable to similar contexts where teachers face comparable challenges. Acknowledging this limitation underscores the importance of the rich, context-specific insights that emerged from detailed engagement with each case.

Figure 3.1 demonstrates how the paradigm chosen influenced the research design and how the research design influenced the sampling strategy.



*Figure 3.1: The Interconnection between Research Paradigm, Research Design, and Sampling Strategy*

The study involved secondary school mathematics teachers who are teaching in the Further Education and Training (FET) phase which comprises grades 10, 11 and 12. However, grade 12 was excluded due to the work commitments at this level. The study involved a total of eight participants: three came from one township school (School A) while the other five participants came from two rural schools (two from School B and three from School C). While it was envisaged to work with four schools (two participants from each school totalling to eight participants), this was derailed by School D (with two participants) pulling out before the initial data-generation process. Two additional participants were recruited from the existing schools to make up the eight previously achieved.

Teachers of different grades follow different teaching plans. Therefore, working with specialists in different grades should offer more meaningful insights. The FET phase was selected because at this stage, students have already chosen their streams which reflect what they intend to study after secondary school.

The researcher is acquainted with the schools at some level and has been a high school mathematics teacher for six years in the same district. This is in line with convenience sampling where participants are recruited based on geographical location and relationships (Arrogante, 2022). Table 3.4 summarises the characteristics of all the participants of the study.

*Table 3.2: The participants' characteristics*

Pseudonym	School	Location type	Phase teaching	Qualification
P1	A	Rural	GET	BEd Hon
P2	A	Rural	GET+FET	BEd
P3	A	Rural	GET+FET	BEd
P4	B	Township	GET+FET	BEd Hon
P5	B	Township	GET+FET	BEd
P6	B	Township	GET+FET	BEd
P7	C	Rural	GET+FET	BEd
P8	C	Rural	GET+FET	PGCE

### **3.5. DATA-GENERATION METHODS**

The following sections present the methods that were employed in this study to generate data. The methods are presented in the order in which they were carried out.

#### **3.5.1 Focus Group Discussions**

Focus group discussions are a qualitative method used to collect rich descriptive data from small groups of participants who have agreed to engage in a specific topic (Mwilongo, 2025; Basnet, 2018; Birmingham & Wilkinson, 2003). This was the initial data-generation method used for this study. While there is no consensus on the optimal number of participants for a focus group discussion, six to eight participants are favoured over 10 to 12 participants since six to eight participants allow for more in-depth discussions (Busetto et al., 2020; Dzino-Silajdzic, 2018). This range is also supported by several recent studies that employed 4–8 participants per focus group as a standard practice to promote meaningful interaction and idea sharing (Bekele & Ago, 2022; Carlsen & Glenton, 2011; Hennink & Kaiser, 2022). All eight selected participants engaged in the focus group discussion which is in line with the suggested numbers per group. To obtain rich data, the questions posed were open-ended and invited the participants to express themselves more freely (Oranga & Matere, 2023; Paradis et al., 2016).

Focus group discussions (FGDs) were chosen for their ability to generate rich insights into participants shared and divergent experiences within a collaborative setting (Busetto et al., 2020). In this study, FGDs were guided by an interview schedule (Appendix A1), which included open-ended questions such as: “What challenges do you face when trying to use ICT tools in your mathematics teaching?” and “How do you perceive the role of ESD in mathematics education?”. These prompts encouraged teachers to reflect on their practices and share contextual challenges and opportunities related to ESD and ICT integration

To avoid disruption at the schools, the FGDs were held after school at School C. Hosting an FGD at each school was not viable since the number of participants would not have been sufficient for each FGD. The 48-minute discussions were facilitated by the researcher and were audio-recorded. The session was guided by the FGD interview schedule (Appendix D). The recordings were then transcribed by an accredited transcriber and analysed by the researcher.

### **3.5.2 Professional Development (PD)**

The PD programme was conducted after the FGDs. The PD was held at a conference venue in Durban. All costs were covered by the funding of the major project. The costs included the transportation of the participants, their refreshments, stationery, ICT tools, and the venue. The participants had to bring their own mobile devices and/or laptops.

Two PD sessions were run to accommodate the participants’ schedules. During the PD sessions, no data was collected as the focus was on capacitating mathematics teachers on ESD integration through ICT in mathematics education.

The selection of ICT tools presented during the PD session was informed by their accessibility, relevance to mathematics teaching, and potential to promote interactive and participatory pedagogies (Jeong & González-Gómez, 2024). Tools such as Kahoot and Blooket were chosen for their capacity to support gamified learning, while GeoGebra enabled dynamic visualisation of mathematical concepts. ChatGPT was introduced to demonstrate AI-assisted lesson planning, illustrating how emerging technologies can support teachers in contextualising ESD themes in mathematics (Mhlabathi & Achieng, 2024)

Each session lasted seven hours. Three participants pulled out of the study. As a result, a total of five participants were available for the PD. The three participants from School A were trained during the first session while the two participants from School B and School C were trained during the second session.

The following were presented during the PD:

- An overview of ESD globally and locally, highlighting its relevance to South African education (expert guest speaker)
- A presentation on how ICT can play a role in promoting ESD
- Two lesson plans that promote ESD through ICT (presented by the researcher)
- Various ICT tools (free and paid) that the participants could use in their lessons (Kahoot, ChatGPT, GeoGebra, Blooket, Centimetre, etc.) (presented by the researcher)
- Interactive activities that allowed the participants to work with some of the ICT tools (Kahoot, ChatGPT, GeoGebra, Blooket, Centimetre) (facilitated by the researcher)
- The design of lesson plans where the participants designed their own lesson plans using templates presented by the researcher. These lesson plans were the ones that the participants used during the observations.

### **3.5.3 Observation**

After the Professional Development sessions, a second set of data was gathered through observation. Observation is defined as a data-generation procedure where the researcher is not an active participant (Harrell & Bradley, 2009). During this time, the researcher focused on the teachers' use of ICT to promote ESD. This included the ICT tools used for planning and lesson delivery, their effectiveness, and the pedagogical approaches used to promote ESD. All five participants who attended the PD were observed. The researcher communicated with each participant via calls and messaging to create a schedule for the observations. Each participant had to share the date and time for the observation. Dates and times were negotiated where there were clashes. Throughout the observations, the researcher maintained professional conduct and complied with all the rules of the school, the Department of Education (DoE), and the constitution to ensure that students are not compromised or made uncomfortable in any way or form. In this

study, the researcher was a silent observer who did not participate in the teaching and learning experience. The researcher observed the full lesson (1 hour) guided by the observation schedule (Appendix E) to collect data that directly responds to the study's research questions and objectives. The observation schedule guided data collection by focusing on specific aspects such as the types of ICT tools used, teacher-student interactions during ICT-supported activities, and pedagogical strategies for integrating ESD themes (e.g., sustainability-related data sets or simulations). These observations aimed to provide insights into how professional development translated into classroom practices. Observing the full lesson offered the researcher the opportunity to generate data from all stages of the lesson.

#### **3.5.4 Post-observation interviews**

With the number of participants dropping to five and the teachers stressing about commitments regarding upcoming examinations, post-observation FGDs were no longer a feasible option. As a result, post-observation interviews were done to gather information on the experiences of the participants regarding the Professional Development sessions, and the integration of ESD into mathematics lessons through ICT. This was a reflective practice for the participants, allowing them to critically reflect on their experiences of implementing the skills and knowledge they have gained from the Professional Development session. Insights from this phase indicated that for effective ESD integration through ICT, continuous Professional Development is required. The participants indicated challenges such as restricted access to ICT resources at their schools, and restricted access to the internet which could have enabled teachers to better engage in sustainability issues. These sessions were meant to take place shortly after each lesson. However, as the teachers had to prepare for other classes, they were given the post-observation interview schedule and asked to send their responses via voice notes on WhatsApp later that day.

Post-observation interviews allowed teachers to reflect on their experiences of implementing ESD through ICT in their mathematics lessons. Example questions included: "How did the students respond to the ICT tools you used?" and "What support would you need to integrate ICT and ESD more effectively in future lessons?". These reflective prompts were designed to uncover perceived benefits, challenges, and areas for improvement in using ICT to promote ESD (Othman et al., 2024).

Research triangulation, which is intended to validate research findings, involves using multiple approaches to obtain required intel and a critical analysis of the findings (Bans-Akutey & Tiimub, 2021). While other data was generated as part of the larger project, this study generated data through focus group discussions (FGDs), observations and post-observation interviews.

Figure 3.2 illustrates the sequence in which data was generated followed by a detailed description of each stage.

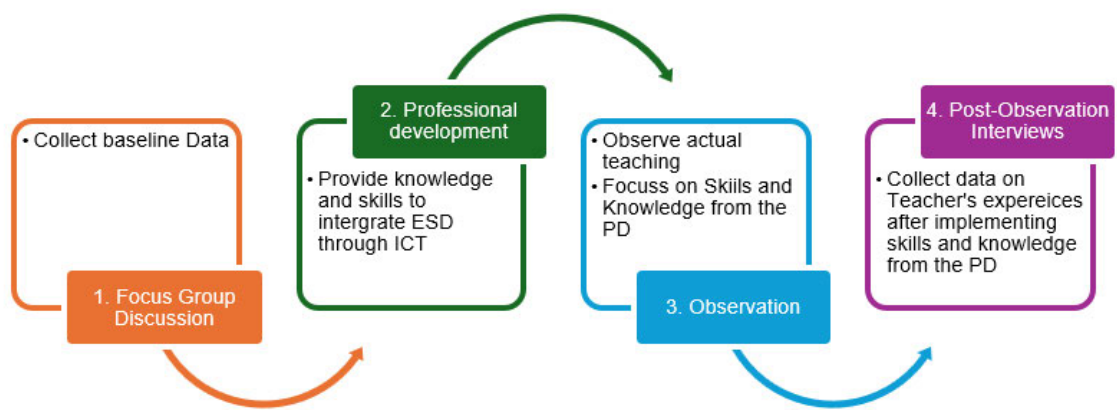


Figure 3. 2 The Data Generation Process

### 3.5.4 Data Analysis

The FGD, observations, and post-observation interviews yielded qualitative data. Thematic Data Analysis (TDA) was therefore used to analyse the data (Nowell et al., 2017). This approach is often used in qualitative studies as it offers researchers theoretical flexibility which results in a more relevant and meaningful analysis (Lester et al., 2020). Furthermore, Miles and Huberman (1994), as cited in Lester et al. (2020, p. 89), stated that “it is common to sort and sift through the data set to identify similar phrases and/or relationships, a practice that has been described as being common across many qualitative analytic approaches”.

Although there are various TDA methods, those proposed by Braun and Clarke (2006) have been widely adopted for qualitative data analysis (Kiger & Varpio, 2020). This study adopted Braun and Clarke’s Reflexive TDA (2022). This work refines the original

2006 framework, emphasising researcher reflexivity and flexibility in the analytic process. They stress that thematic analysis is not a single prescriptive procedure but a theoretically flexible “family” of methods; their approach – now called Reflexive Thematic Analysis – is one member of that family, characterised by the active role of the researcher in theme development (Braun & Clarke, 2022). Braun and Clarke (2022) outlined six recursive phases (often informally called “steps”) for conducting Reflexive TA:

*Phase 1: Familiarising yourself with the data*

This step requires the researcher to become familiar with the data by actively reading the data set repeatedly and making informal notes about potential meanings (Braun & Clarke, 2022). In this study, data came from the Focus Group Discussion (in audio form), Observation (in typed format) and, lastly, the Post-Observation Interviews (in audio form). All audio was transcribed into text. The researcher then read the transcript and observation schedule repeatedly to get used to the data.

*Phase 2: Coding*

This step involves generating concise labels (codes) that highlight important features about the data (Braun & Clarke, 2022). The researcher worked through the entire dataset of each instrument tagging segments of text that were interesting and recurring. According to Braun and Clarke (2022), Reflexive TA allows the researcher to move back and forth. Therefore, during this phase, labels were reviewed and changed several times. This way, the researcher was able to somewhat group some data items.

*Phase 3: Generating initial themes*

This phase was initially called “searching for themes”. However, the themes are not readily available; they are built by the researcher in this “meaning-making process”. This phase involved examining the codes and their associated data to identify broader patterns of meaning – i.e., potential themes (Braun & Clarke, 2022). The researcher grouped and compared the codes to get a better understanding of the relationships. Codes were grouped according to the two theoretical frameworks. All three elements of Msafiri’s ICT Integration Framework and all four elements of Nerstrom’s

Transformative Learning Model were used to group codes. Note that there was insufficient data to place under Nerstrom's Transformative Learning phase. During this phase, a new perspective is adopted, and the teacher voluntarily uses the newly acquired knowledge and skills (Nerstrom, 2014). The researcher did not randomly visit the schools to check if the participants voluntarily adjusted their practices.

*Step 4: Developing and reviewing the themes*

This step involves checking if the coded data is a proper fit under a specific theme and if the theme is representative of the data set (Braun & Clarke, 2022). The researcher checked for coherence among themes and checked that the data within each theme is coherent. The researcher made use of the thematic map to understand the relationships between themes while ensuring that the thematic map also represents the entire data set.

*Step 5: Refining, defining, and naming the themes*

This step involves creating definitions and narrative descriptions of themes and justifying their significance in terms of the broader study questions (Braun & Clarke, 2022). The researcher refined the names of the themes to ensure they speak to the research questions and study objectives. The researcher also ensured that the constructed themes correspond with the two theoretical frameworks.

*Step 6: Writing up (producing the report)*

The final step involves the final analysis write-up and the description of the findings (Braun & Clarke, 2022). The researcher provided a detailed write-up of the analysis and presentation of the findings. The write-up included a synthesising table highlighting the alignment of themes, theoretical frameworks and research questions.

The coding and theme development process was guided by the two theoretical frameworks underpinning this study. For example, codes related to Professional Development, ICT Integration, and Problem Identification were grouped under Msafiri's ICT Integration Framework, while codes reflecting shifts in teacher perspectives were aligned with phases of Nerstrom's Transformative Learning Model. This framework-based organisation of codes ensured that the analysis remained theoretically grounded and focused on the study's objectives.

Reflexivity was an important aspect of the analysis process. The researcher's prior experience as a mathematics teacher in the same district provided valuable contextual understanding but also posed a risk of bias. To mitigate this, the researcher engaged in critical self-reflection and peer discussions during coding to ensure that emerging themes were drawn from participants' voices rather than preconceived assumptions.

While Braun and Clarke's Reflexive Thematic Analysis (2022) offers flexibility and depth, its reliance on researcher interpretation can risk overlooking subtle or less dominant themes. This limitation was addressed by maintaining detailed audit trails and revisiting the data iteratively to ensure that all significant patterns were captured.

### **3.6 VALIDITY AND RELIABILITY**

This study adopted a multiple case study approach which is aligned with the interpretivist paradigm. However, case studies (including multiple case studies) focusing on unique phenomena often pose challenges regarding reliability and validity (Bassey, 1999). Acknowledging the difficulty of attaining similar levels of validity and reliability in qualitative research compared to quantitative research, scholars have proposed qualitative equivalents that mirror established quantitative validation methods (Creswell & Poth, 2016). Guba and Lincoln (1994) identified four alternative criteria – credibility, transferability, dependability, and confirmability – which are more appropriate for establishing the trustworthiness of naturalistic research.

#### **3.6.1 Credibility**

Credibility is defined as the extent to which findings reflect complete, truthful, and reasonable explanations of a case (Baumgart et al., 2021). Credibility can be established through persistent observation, prolonged engagement and data generation triangulation (Guba & Lincoln, 1994). Similarly, Creswell and Poth (2016) suggested that the triangulation of data sources and engagement with participants over an extended period enhance credibility. The researcher maintained extended interaction with the participants through the FGD, Professional Development session, and observations. Furthermore, data was generated through multiple sources (FGD, observations and post-observation interviews).

### **3.6.2 Transferability**

Transferability depends on the researcher's ability to provide thick and rich accounts of the time and context of the study (Lincoln & Guba, 1985). This study offered clear and rich descriptions of the characteristics of the participants and the natural environment in which they were observed, and of the theoretical and methodological choices. This helps to ensure that the findings of this study are transferrable to similar settings.

### **3.6.3 Dependability**

Data-generation and analysis processes should be described in thick detail to allow other researchers to follow the same steps (Stenfors et al., 2020). Ensuring dependability requires researchers to maintain a well-documented, coherent, and transparent research process that allows others to follow the logical flow of the study (Nowell et al., 2017). This study offered clear and detailed descriptions of how the data was generated, analysed, and informed by the theoretical frameworks and research paradigm.

### **3.6.4 Confirmability**

Confirmability is concerned with the extent to which the findings reflect the data collected (Kyngäs et al., 2020). This study sought to achieve credibility, transferability and dependability and then to establish confirmability (Lincoln & Guba, 1985). Furthermore, graphical representations (tables) demonstrate how the researcher arrived at the findings (Cloutier & Ravasi, 2021). The study includes graphical representations of the theoretical frameworks which informed the data-generation methods and analysis. Some data is presented in tables to highlight the alignment of themes, theoretical frameworks and research questions.

To strengthen confirmability, this study maintained a detailed audit trail that documented each step of the research process, including methodological decisions, coding processes, and theme development. This transparent record ensures that the findings can be traced back to the original data. Consistent data collection methods (using the same interview and observation protocols across cases) also helped reduce potential bias and enhance the reliability of the findings. By aligning codes and themes with the theoretical

frameworks (Msafiri's ICT Integration Framework and Nerstrom's Transformative Learning Model), the researcher ensured that interpretations were grounded in both the data and established theory rather than personal assumptions.

### **3.6.5 Audit Trail**

An audit trail provides a transparent record of the researcher's methodological and theoretical choices, offering justification for key decisions made throughout the study (Koch, 1994). The rationale for the methodology and theoretical choices and decisions in this study has been built on an extensive literature review while at the same time maintaining consistency throughout the study.

### **3.6.6 Strategies to Enhance Credibility**

To strengthen the trustworthiness of the findings, this study employed several strategies. Triangulation was used by drawing on multiple data sources (focus group discussions, classroom observations, and post-observation interviews), which allowed for cross-validation of insights and a more comprehensive understanding of teachers' practices (Creswell & Poth, 2016). Member checking was conducted by sharing preliminary interpretations with participants to ensure that their perspectives were accurately captured. Additionally, peer debriefing was utilised during the data analysis process, where the researcher engaged with colleagues in the field of mathematics education to reflect critically on emerging themes and minimise potential biases (Nowell et al., 2017).

These strategies align with the principles of qualitative inquiry, ensuring that the findings are credible and reflective of the participants' experiences in integrating ESD through ICT in mathematics teaching.

## **3.7 ETHICAL CONSIDERATIONS**

Ethical consideration calls on researchers to address issues of confidentiality, anonymity, consent, human dignity, and privacy as a means to avoid physical and psychological human harm (Muzari et al., 2022).

According to Lincoln and Guba (1985), participants can be protected from harm and privacy issues through anonymity. Hence, pseudonyms have been allocated to the schools and the participants to protect both from harm and privacy issues. Personal information (biographical data) was not shared with any third party. This information was only shared with the University of KwaZulu-Natal as part of required appendices. All data collected for this study is locked in a safe at the university and will be destroyed after five years.

Ethical approval for the study was granted by the university (Protocol reference number: HSSREC/00006730/2024) (Appendix G), and permission from the departmental head and the heads of the schools. Consent forms were properly designed to inform the participants about the study's intent and their rights as participants, and to make it clear that participation is completely voluntary and that they can withdraw at any time. Given that the data-generation process included an observation phase, students and parents were provided with consent and declaration letters. This helped to ensure strict adherence to ethical processes throughout the study.

While the ethical protocols adhered to in this study ensured a high standard of confidentiality and anonymity, additional measures were in place to address potential ethical dilemmas. For example, had any participant expressed discomfort during data collection, the session would have been paused immediately, and guidance sought from the university ethics committee to resolve the issue appropriately.

During the classroom observation phase, parental consent and learner assent were obtained to ensure that students' rights and dignity were fully protected. These measures were especially important given the inclusion of minors in a naturalistic classroom setting

While no major ethical dilemmas arose during the study, the researcher was prepared to address potential challenges such as participant discomfort or inadvertent breaches of confidentiality by immediately pausing data collection and consulting the ethics committee if necessary.

### 3.8 CONCLUSION

The research methodology of the study was presented in this chapter. This included a table summarising the alignment between the research objectives and research questions, instruments and analysis method. Next, the paradigm that underpins the study was discussed, drawing from literature to support the choice. Thereafter, the research design was discussed which included a diagram of how the paradigm influenced the research design (multiple case studies), which influenced the choice of sampling strategy (purposive). The sampling strategy was outlined to justify the sample size and the participants' profiles were presented. It was explained why the data-generation process (FGD, observations and post-observation interview) provided thick descriptions of the phenomena being studied. This section also featured a diagram of the data-generation sequence. This was followed by a discussion of the data analysis process using Braun and Clarke's Reflexive Thematic Analysis (2022). Each phase of Braun and Clarke's Reflexive TA approach (2022) was outlined. This was followed by a discussion of how validity and reliability was achieved. Lastly, the ethical considerations underpinning the study were explained. The following chapter presents the generated data and provides an analysis of the key findings.

The methodological choices outlined in this chapter were carefully aligned with the study's objectives and theoretical frameworks. By adopting a qualitative multiple case study design and employing data generation methods such as focus group discussions, professional development, classroom observations, and post-observation interviews, this study prioritised depth and context in understanding teachers' experiences. The integration of Braun and Clarke's Reflexive Thematic Analysis ensured that findings were grounded in participants' perspectives while maintaining alignment with the conceptual frameworks. These strategies collectively contribute to the rigor, trustworthiness, and relevance of the study's findings.

# Chapter 4 | Data Presentation & Analysis

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## 4.1. INTRODUCTION

This chapter presents the qualitative data gathered and an analysis of the data using Braun and Clarke’s Reflexive Thematic Analysis (2022). Data was generated through three instruments. The design of these instruments was guided by two compatible theoretical frameworks: Nerstrom’s Transformative Learning Model, which provides a lens for understanding the integration of ESD through ICT, and Msafiri’s ICT Integration Framework, which offers insights into how ICT can facilitate this integration. The data generated was intended to respond to three main research questions of this study.

While the two theoretical frameworks provided conceptual guidance for the study, they also directly shaped the data analysis process. Nerstrom’s Transformative Learning Model (2014) informed how the researcher interpreted teachers’ reflections and responses, particularly in identifying evidence of perspective shifts toward sustainability and critical thinking. Meanwhile, Msafiri’s ICT Integration Framework (2023) provided a structure for analysing how ICT tools were applied or underutilised in mathematics teaching to support ESD. By aligning emerging themes with these frameworks, the researcher ensured that the analysis remained grounded in the study’s conceptual foundations without imposing external assumptions on the data.

*Table 4.1: Alignment of Themes and Subthemes with the Research Questions and the Theoretical Frameworks*

	<b>Theme</b>	<b>Subtheme</b>	<b>Research Questions</b>	<b>Theoretical Framework</b>
<b>1.</b>	Awareness and Understanding of ESD	Teachers’ understanding of ESD	RQ 1	Nerstrom’s Transformative Learning Model
		Teachers’ implicit integration of ESD	RQ 1	Nerstrom’s Transformative Learning Model

		Perceived benefits of ESD integration	RQ 1	Nerstrom's Transformative Learning Model
		Barriers to effective ESD integration	RQ 1	Nerstrom's Transformative Learning Model
2.	ICT Integration in Mathematics Teaching	ICT tools teachers used	RQ 1 & 2	ICT Integration Framework
		Teacher-led initiatives with ICT	RQ 2	ICT Integration Framework
		Barriers to effective use of ICT	RQ 2	ICT Integration Framework
3.	Professional Development for Teachers	Professional Development received	RQ 3	Nerstrom's Transformative Learning Model and ICT Integration Framework
		Teachers' experiences with Professional Development provided	RQ 3	Nerstrom's Transformative Learning Model and ICT Integration Framework

Table 4.1 highlights the alignment of the research questions, themes and subthemes and the underpinning theoretical frameworks. It also shows the sequence in which the data will be presented in this chapter.

Table 4.2 shows some of the biographical details of the participants. References to the schools make it easy to identify participants from the same school/area.

Table 4.2: The Participants' Biographical Details

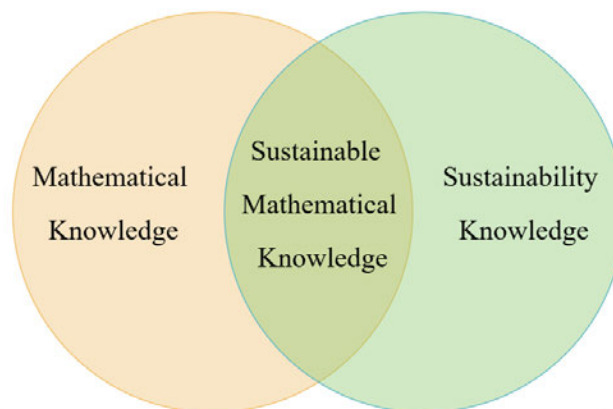
Pseudonym	Years teaching	Qualification	School
Participant 1	10 years	BEd	School A
Participant 2	05 years	BEd	School A
Participant 3	12 years	BEd Hon.	School A
Participant 4	23 years	BEd Hon.	School B
Participant 5	19 years	BEd	School B
Participant 6	10 years	BEd Hon.	School B
Participant 7	05 years	BEd	School C
Participant 8	07 years	PGCE	School C

The theme *Awareness and understanding of ESD* is unpacked in the first section of this chapter. This initial theme (awareness and understanding of ESD) is critical for establishing the foundation of teachers' practices in integrating sustainability into mathematics teaching. By exploring teachers' awareness, the analysis reflects how their knowledge (or lack thereof) shapes their engagement with ESD principles. This also links back to Nerstrom's Transformative Learning Model, which emphasizes that awareness of new paradigms is often the first step in enabling transformative shifts in practice (Nerstrom, 2014).

Teachers already have mathematical knowledge and are seasoned in their field. However, it appears that sustainability concepts are not fully embedded in their teaching. Therefore, they do not possess what the researcher calls sustainable mathematical knowledge (SMK). While SMK is not a widely recognised concept in literature, for the purposes of this study, SMK in teaching can be defined as the development of mathematical understanding, skills, and problem-solving abilities that are applicable in various real-world contexts, especially those related to sustainability, environmental awareness, and long-term societal needs. Traditional mathematical knowledge often focuses on abstract problem-solving and procedural fluency, with limited emphasis on contextual applications that address real-world challenges (Minott et al., 2020). In contrast, Sustainable Mathematical Knowledge (SMK) incorporates

both mathematical proficiency and sustainability principles, enabling learners to apply concepts in ways that promote environmental stewardship, social equity, and economic viability. This contrasts with conventional approaches where mathematics is often taught in isolation from such global issues (Teise & Le Roux, 2016). Positioning SMK in this way highlights its relevance to contemporary education and addresses a gap in literature on how mathematics can empower learners to engage critically with sustainability challenges.

SMK emphasises teaching mathematics in a way that fosters critical thinking, responsible decision-making, and the ability to apply mathematical reasoning to global challenges such as climate change, resource management, and financial literacy. This study promotes an ideal that teachers must have both mathematical and sustainability knowledge (which refers to an individual's understanding of the principles, concepts, and practices that promote environmental, social, and economic well-being in a way that ensures the long-term health of the planet and future generations) which should be evident in their practices. Figure 5.1 shows the intersection of sustainability knowledge and mathematical knowledge.



*Figure 4.1: The Intersection of ESD and Mathematics*

## **4.2. AWARENESS AND UNDERSTANDING OF ESD**

In the South African context, ESD is characterised by an approach to education that is holistic and integrated; values-driven; comprised of critical thinking; geared towards problem-solving and action; and multi-methodological and participatory (Teise & Le Roux, 2016). The focus group discussions (FGDs) revealed that all the participants are

generally unaware of the concept of ESD and of the SDGs. Of the eight participants, 87.5% (7 out of 8) indicated they were unaware of the concept of ESD and the SDGs, while only 12.5% (1 out of 8) demonstrated partial awareness. However, their current practices do have a few ESD determinants, and some participants demonstrated some idea of what sustainability entails.

#### 4.2.1 Understanding of Sustainability Concepts

When the participants were asked to share their understanding of the concept of ESD, some offered explanations while Participant 5 stated outright that they had never heard of the concept before:

*I'm hearing the concepts for the first time. So, I'm still trying to wrap my standing around it.*

Next, the researcher asked the participants to share their understanding of the concept of sustainable development in general. Most of the participants offered explanations suggesting that they are not very knowledgeable about the concept of sustainability even though some had a vague idea. Participant 7 attempted to define sustainable development, showing some understanding of the concept:

*Sustainable development ... so, I think from what I'm understanding, it's how we conserve nature around us ... Something like that.*

Vague definitions of sustainability were also offered by other participants:

**Participant 4:** *Off the top of my head ... For me, I think it would mean whenever I do or decide to do in terms of the model or it is something that technology – it has to be something that I can keep going for as long as it is needed. It's not something that will happen once and it doesn't carry on.*

**Participant 6:** *I think it's something that we use in class, like, even if we are using the textbooks just to accommodate every learner in class.*

**Participant 8:** *I don't know whether I will explain it clearly. Okay, it's about the new... it's a new system or new technology for our learners to be able to*

*overcome the challenges that we face in life. Dealing with the things that they are dealing rather than in the past. So, it's a new...*

Participant 1 was not teaching at a private school at the time of the study but had some exposure to the concept while teaching at a private school some years back. He added:

*Here in public schools, there are no such things like that. Or they are but they are not using them. In previous years I was in private schools. There were some readings on that, but I never read that. I didn't read that document. There were some posters on the wall, but I can't remember that.*

Participants 2 and 3 also offered very vague explanations of their understanding of the concept of ESD or sustainable development. What was also concerning was how the teachers struggled to articulate their ideas in English which is the medium of instruction in all the schools involved in the study – this was despite the fact that some of the participants had more than 10 years of teaching experience. Furthermore, Participant 1 alluded to the idea that private schools may have initiatives geared towards ESD integration or at the very least spreading awareness about it. Moreover, when the participants were asked to list any of the UN's 17 Sustainable Development Goals, none of them could name any which confirms that teachers in peri-urban areas are not aware of ESD.

This lack of knowledge resulted in the Professional Development session that was later provided by the researcher. This finding underscores the importance of transformative learning in reshaping teachers' perspectives. Nerstrom's Transformative Learning Model highlights how exposure to new concepts, such as ESD and SDGs, can challenge existing assumptions and catalyse a shift towards more reflective and sustainability-oriented teaching practices (Nerstrom, 2014). By situating Professional Development within this theoretical framework, the study aligns teacher learning with broader goals of educational transformation.

This lack of knowledge also prompted the researcher to offer some background on ESD and the 17 Sustainable Development Goals during the FGDs. After the Professional Development session, all the participants who allowed the researcher to observe their lessons (Participants 1, 2 and 3) covered ESD determinants and the promotion of

sustainability practices in their teaching content. Participant 1's lesson promoted the procurement and use of sustainable resources while Participant 2's lesson promoted sustainable financial practices and Participant 3's lesson encouraged sustainable car choices based on fuel consumption and the demand for more natural resources to be used.

This progression from initial unfamiliarity to integrating ESD principles in their lessons aligns closely with Nerstrom's Transformative Learning Model. The model illustrates how exposure to new ideas and critical reflection can disrupt entrenched pedagogical assumptions and facilitate transformative shifts in teaching practices. Additionally, Msafiri's ICT Integration Framework offers strategic insights into how sustained professional development, supported by appropriate ICT tools, can empower teachers to embed ESD concepts in mathematics classrooms despite contextual constraints.

#### **4.2.2 ESD Integration in Practice**

After the brief background on the SDGs provided by the researcher during the FGD session, Participant 2 commented:

*Yeah, I think with that it starts from the textbooks that we have because I can say teaching for the sustainable development is done but indirectly and we are not so close to it because if we can take a look to each and every like topic, there is a sort of address that is this topic is addressing and it can be used to, to just sustain, sustain, to sustain sustainable development.*

Here, the participants realised that some of their practices may already incorporate elements of ESD indirectly. Participant 2 further commented:

*So, then as I'm getting surprised how we are using statistics in charging people like as, uh, what is this thing, uh, as municipalities using statistics and where are these questions coming from, you know? It's hard for them to relate because we are not told, we, they are not told that these topics are those people who are doing. It doesn't give a clear direction to the sustainability of the ... to the sustainable development of some of in the near future because it's just a topic to understand ...*

Participant 2's comment highlights the fact that topics like statistics are difficult for learners to grasp because they cannot connect them to real-life contexts and there is no clear direction on how to teach these concepts in a way that learners relate to. Here, teachers have an opportunity to promote critical thinking around municipal issues that may be common, like raising municipal tariffs and actions that can be taken to deal with issues, which is in line with the five ESD characteristics in the South African context (Teise & Le Roux, 2016). Participant 1 affirmed what Participant 2 had alluded to:

*And you hear people who are saying, 'Why are we doing maths?' because we don't apply it in real life.*

This implies that when the participants are teaching, the focus is not to get the learners to apply what they have learnt in their lives (which is sustainable) but rather to just be able to write exams. Participant 1's comment also highlights a disconnect between mathematics and real life and this is a perception carried by their learners. In all the lessons observed, the teaching style was teacher-centred with very little opportunity for the learners to collaborate on sustainability issues even though collaboration is one of the key characteristics of ESD (Zickafoose et al., 2024). Most of the time, the learners were merely repeating after the teacher which contradicts one of the five characteristics of ESD in the South African context which is fostering critical thinking (Teise & Le Roux, 2016). This observation reflects how traditional, teacher-centred pedagogies often fail to engage learners in meaningful discourse. ESD emphasises participatory and collaborative approaches to learning that empower students to apply knowledge critically and creatively in real-world contexts (UNESCO, 2022). Encouraging a shift from passive absorption of information towards active engagement is therefore essential in equipping learners with the skills needed for sustainable development.

Participant 3 expanded:

*... the normal traditional way of teaching them just takes over because when you started out, you had the passion. You did tell them what this topic is going to help you in future and how this is amazing. But as time went on, normal traditional way of teaching – you just teach maths for them to know and then give you ... But I think the traditional way of ... teaching and education just took over and then ... Let's just do it and for them to pass.*

Participant 3, who had over 10 years of teaching experience, alluded to the fact that motivation deteriorates over time. This deterioration of motivation underscores the critical role of systemic support in sustaining innovative teaching practices. As noted in Msafiri et al. (2023), teachers require not only access to ICT tools but also ongoing encouragement and capacity-building initiatives from school leadership and education departments to maintain enthusiasm for integrating ESD into mathematics teaching. Without such support, even experienced teachers may revert to conventional methods that prioritize curriculum coverage over transformative learning.

This makes one wonder about the kind of support they received from the management teams of the schools and the Department of Basic Education and about the availability of resources (like ICT tools) for effective teaching. It appears (for Participant 3 at least) that the traditional way of teaching is one where learners do not know why they are learning what they are learning, and where the primary focus of education is to “*just do it and for them to pass*” (Participant 3). As Nerstrom (2014) suggested, teachers’ experiences have created assumptions that it is best to just teach learners to pass and that this has now become the “traditional way of teaching”. Furthermore, calling it a tradition suggests that this is not something unique for this participant – it has become widely accepted.

Participant 5 offered the following after the brief explanation of the meaning of ESD and sustainable development:

*Now that you are mentioning that – with teacher 4, we taught the ... they call them world graphs ... Global graphs, where you are given a graph which is telling you that in such a year we had so many rhinos ... and so on. Then learners will actually relate these to nature, the big five and stuff like this. And then we make them aware that we have this problem of rhinos being poached, because some questions in the end, they will actually ... require learners to apply their mind into what they think should be done in terms of saving the rhinos because they are certain options which are there.*

Kopnina (2020) discussed ecopedagogy or ecocentric education as another approach to ESD. Such education teaches learners to care and appreciate nature throughout their lives (Kopnina, 2020). For example, rhino poaching is a problem in South Africa and

learners may be aware of this as it regularly features in the media. Having learners critically engage with this topic may prevent them from participating in such activities later in life (which would be sustainable). Furthermore, Kopnina (2020) describes planetary citizenship as a continuous process that extends beyond the classroom into the broader community, encouraging learners to cultivate a sense of responsibility for planetary inclusiveness, where collaboration and coexistence with other species are normalized. Hence, it appears that Participant 5 has already been promoting planetary citizenship and integrating ESD without realising it. Education like this is connecting mathematics to real life and potentially contributes to preventing people becoming poachers in the future. Hence, a sustainable future is promoted.

This approach demonstrates how contextualising mathematics within pressing socio-environmental issues can move learners beyond passive consumption of knowledge to active, critical engagement. By analysing global graphs on rhino populations and debating possible interventions, learners are required to evaluate complex systems and consider multiple perspectives, fostering skills such as reasoning, argumentation, and ethical decision-making. These activities stimulate higher-order thinking by challenging students to connect abstract mathematical concepts to real-world problems and assess the implications of human actions on biodiversity. Moreover, situating lessons in a familiar and culturally relevant context increases learner motivation and emotional investment, making the learning experience more memorable and impactful. As learners begin to question, model, and propose solutions, they develop not only mathematical literacy but also a deeper awareness of their roles as problem-solvers in their communities. This suggests that contextualised teaching is a powerful tool for cultivating the critical consciousness essential for transformative learning and sustainable development.

Participant 6 added the following in this regard:

*To add on what teacher 5 said, sometimes in statistics we have to compare the learners' marks like in mathematics, if the learner is getting 60 and then in physics he is getting 70. So, the possibility of getting maybe 80 in maths, and maybe in physics it would be 80 something. So, yes, it's happening.*

Participant 6 solidified the fact that the participants are indeed integrating ESD in their teaching, even if unintentionally so. This could also mean that the participants subconsciously know that education should be made relevant in the learners' lives. For example, instead of using arbitrary examples like the costs involved in booking a flight (when none of the learners has set foot in an airport), the teacher could use learner test scores which is something with which they are very familiar. Test scores can be used by individual learners to make predictions, and plan interventions and goals for future assessments.

While the participants initially demonstrated limited awareness of ESD and sustainability principles, their reflections during the focus group discussions revealed a willingness to learn and adapt. This suggests that teachers possess latent potential to integrate sustainability concepts into their mathematics lessons if provided with appropriate support and exposure. Such openness aligns with the transformative aspects of Nerstrom's model, where shifts in understanding are triggered through dialogue and critical reflection (Nerstrom, 2014).

The data generated indicated that, even though at first the participants were not aware of ESD or the SDGs, they could see the potential benefits or importance of integrating ESD into mathematics teaching once the concepts had been explained to them.

These findings reflect how teachers' latent potential to integrate ESD principles can be activated through targeted professional development and contextualised teaching strategies. Nerstrom's Transformative Learning Model provides a lens for understanding how exposure to new sustainability concepts and critical dialogue can challenge entrenched teaching traditions, enabling perspective shifts towards more participatory and reflective pedagogies. Simultaneously, Msafiri's ICT Integration Framework offers strategic insights into sustaining this momentum by embedding ICT-supported resources and capacity-building initiatives within institutional structures. Together, these frameworks underscore the importance of aligning teacher support systems with broader sustainability goals to transform mathematics education in meaningful ways.

### 4.2.3 Benefits of ESD/Sustainability infused mathematics lessons

The participants were asked the following question: “Thinking back on your experiences, can you share any positive outcomes or benefits you observed when integrating education for sustainable principles into mathematics lessons?” Participant 8 responded in this way:

*Yeah, for its benefits. They understand more easily when you use examples that are more related to them as opposed to something they do not know.*

Participant 8’s statement underscores the importance of contextualising education by using examples that learners can relate to. This implies that if mathematics teachers connect mathematical concepts with the lived experiences of learners, there may be noticeable improvements in engagement and understating. This approach aligns with the principles of ESD, which advocate for relevance and real-world applicability in learning to foster critical thinking and problem-solving skills (Minott et al., 2020).

While all lessons observed were teacher-centred, all teachers did pose questions that fostered critical thinking through frequent questioning. The learners of Participants 1 and 3 were able to respond while the learners of Participant 2 struggled to answer questions. For example, Participant 1 was teaching measurements and used African huts or rondavels to identify shapes. He projected high-quality images onto the screen and learners were able to identify different geometric shapes, leading to discussions about buying materials to build the rondavel.



*Figure 4.2: Participant 2's Lesson on Measurements*

The emphasis was on accurate calculations so that accurate orders/purchases of materials could be made, and loss could be minimised when building a rondavel. These are mathematical skills the learners can use immediately at their respective homes (advising their elders) which could potentially save money for their families.

Participant 3's lesson covered loans, investments, interest rates and repo rates. The focus here was on making better financial choices. Such topics can put learners in a better position to educate their parents and to make better financial choices themselves.

Participant 1's lesson had very limited engagement. The lesson was on angular movement with a strong focus on the speed of fast cars. The teacher displayed high-quality images of fast cars and their top speeds. The choice of fast cars may be more interesting to male learners than female learners (Wang et al., 2020). Furthermore, given that the schools are situated in a peri-urban area, it is more than likely that most learners at the school come from very poor families. Hence, they may not even have a car at home. The learners appeared very confused throughout the lesson. Perhaps a different and more contextualised example may have resulted in a different outcome. Participant 2 made the following comment in this regard:

*But I think it will be helpful, also even if they can't but see now, that what they're looking at, that they're interested in doing, they really can't. So, if you are giving them the problem that is really there in what they said I'm choosing this career path. If you get the taste of what is really in their career paths, then it means I*

*can change. I must change it now because it's hard to find learners passing higher marks in high school and come to varsity and fail the first year.*

Participant 2 underscored the potential of ESD integration to enrich education by making it more career relevant and supporting informed decision-making and ultimately broader societal goals. This approach can help to ensure that learners are not only academically prepared but also aware of critical aspects of their future fields.

Participant 1 added the following when asked whether ESD could benefit learners and whether it would have an impact in their attitude towards mathematics:

*It will depend on learners, those who understand questions and understand English – they will gain a lot of interest. But those who are really struggling, they are most likely to fail, and they will have negative attitude towards the subject, and they will not be able to attempt questions. Yeah, that's the problem.*

Similarly, Participant 3 added:

*Look at Maths Lit. Maths Lit was designed to come solve the problems that the kids would meet with pure maths. But now with Maths Lit, it's the English. The language will become the barrier because everything is asked, and I will tell you, every question in Maths Lit is realistic. So, they have to look at it in reality, like they tell you that you are going to Mrs. M is building a garden and then you must calculate the dimensions ... It's reality. Yeah, but now the problem is for them to break it down, from the scenario they're given, and then they break it down and see what they need to calculate.*

While Participants 4, 5, 6, and 7 shared the same sentiments as Participants 2 and 8, Participants 1 and 3 highlighted an obstacle that may hinder ESD integration. For Participants 1 and 3, English plays a crucial role in the learners' ability to access mathematical content (especially word problems). Therefore, learners who struggle with the English language may have an additional layer of difficulty which can potentially obscure their understanding of mathematical concepts. Learners already struggling may develop a negative attitude towards mathematics which is the opposite of what ESD intends to achieve. Participants 2 and 3 taught their lessons in English and

their lessons had less learner participation compared to Participant 1 whose lesson was presented mostly in isiZulu, even though the medium of instruction is English for mathematics. While there was more participation during Participant 1's lesson, the learners must still use English when writing their assessments. Therefore, the language barrier may still impact learners' attitudes towards mathematics since in class they might feel that they understand but they struggle to write formal assessments.

Language barriers present a notable challenge to the effective teaching and learning of ESD-related topics in mathematics classrooms. In South African schools, where English often serves as the medium of instruction but is not the learners' home language, students may experience difficulty in comprehending sustainability concepts embedded within word problems and real-world applications. This limitation affects their ability to engage critically with ESD principles and undermines their confidence in applying mathematical reasoning to societal issues such as resource management, financial literacy, and environmental conservation. Teachers also encounter challenges in simplifying abstract sustainability concepts into accessible language without diminishing their complexity. As a result, discussions on climate change, energy efficiency, or sustainable economic practices may fail to resonate meaningfully with learners, particularly in multilingual classrooms. These challenges emphasise the need for professional development programmes that prepare teachers with strategies for simplifying ESD concepts, leveraging multilingual resources, and employing ICT tools to bridge language gaps. Without addressing these barriers, efforts to integrate ESD into mathematics risk perpetuating existing inequalities and falling short of preparing learners for the demands of sustainable development.

These findings underscore the potential of Nerstrom's Transformative Learning Model in helping teachers critically reflect on their current practices and assumptions about mathematics teaching, paving the way for more learner-centred, sustainability-oriented approaches. Furthermore, Msafiri's ICT Integration Framework provides strategic guidance for addressing contextual challenges such as language barriers and resource limitations. By leveraging multilingual ICT tools and fostering professional development programmes that focus on culturally relevant pedagogies, teachers can create inclusive learning environments that promote critical thinking and empower learners to engage meaningfully with ESD concepts.

#### 4.2.4 Challenges to effective ESD integration through ICT

The participants highlighted other hindrances that prevent effective ESD integration. These came to the fore when the participants were asked whether it was feasible to incorporate ESD into their Annual Teaching Plan (ATP). The ATP, which is informed by the CAPS document, prescribes what content should be taught and at what pace. Participant 1 shared the following:

*They don't know how many learners we have in our classes, and they don't know how much impact is done by the meetings that you usually have in our schools. ... they assume that our kids, it's all size fits all. So, their ATP is a problem to us even now... there is going to be more problems.*

Participant 1's comments highlight a deep disconnect between policymakers and the realities on the ground which include large class sizes and additional non-teaching demands like meetings (in school or outside). Overcrowded classroom in South African secondary schools impedes teachers' ability to teach effectively and maintain discipline and ultimately leads to poor performance (Marais, 2016). The comment also criticises the "one-size-fits-all" approach to curriculum planning which disregards contextual differences among schools, referring to resources, teacher workloads and learner capabilities. In such an environment, teachers may not prioritise ESD integration especially if it is not explicitly stated as a requirement in mathematics classes. Participant 3 added:

*And they don't even take into consideration factors like the water issue, yeah. So, the water has been a problem, and the ATP is a problem on its own. So, adding onto it would be even a bigger problem.*

Participant 3's comment touches on a broader socioeconomic problem that affects teaching and learning in that the schools must close when there is no water. This is teaching time lost. This makes the integration of ESD seem even more daunting. According to Water and Sanitation Minister Pemmy Majodina, the growing population in KZN is the reason why there are water issues (eNCA ,2024) which means teaching may be affected until the region is able to overcome its water problems. Participant 1 further elaborated:

*And if they're estimating the number of days, they don't know the impact that has been done by the teachers in the previous grade. Maybe we can find that learners they didn't even cover the topic they were supposed to cover [it] in the previous year. And while you're trying to do revision with the learners you find that nothing has been done on this topic. So, you have to redo that whereas in the ATP maybe you are given 10 days. In that 10 days, we have to start the topic as it was supposed to be covered in the previous grade.*

Participant 1 highlighted another critical challenge, namely the assumption that learners mastered the foundational content from the previous grades whereas in reality, they have significant gaps that now require teachers to allocate time to breach these gaps. Again, the thought of adding ESD integration is a daunting one. The comment also refers to the unrealistic time allocation in the ATP which does not take into account the diverse classroom realities like the varied learner preparedness and the need for additional revision. The challenge is therefore that ESD integration would require ATP restructuring, better time allocation, and systematic support to address the foundational gaps. Without flexibility and support, ESD integration risks being deprioritised in favour of catching up on essential content.

The time issue was evident in all the classroom observations. None of the participants was able to complete the lesson as planned in the time allocated. Participant 1 was asked the following question (during the post-observation interview): “What challenges did you face in lesson planning, managing time and addressing diverse learner needs while integrating ICT for ESD in the lesson?” He then shared the following:

*In lesson planning, one challenge was ensuring that all learners remember formulae they learnt in the previous grade on 2/3D shapes. I thought I was going to revise formulae, but I ended up teaching them. Therefore, time management was another problem. Before the lesson, learners took their time to come to class...*

Reteaching previous grades' content was time-consuming indeed, resulting in the intended lesson not being taught in its entirety as planned. This seemed to happen regularly, which implies little opportunity to prioritise proper ESD integration through ICT. Participant 2 had the following to say in this regard:

*No, for me, I will not even go to ATP people. ATP people doesn't speak with the exam people. They give us ATP, saying we are going to teach Term 1 from Day 1 and maybe say 20 January and we will finish these topics according to the time allocated to the topic. So, we're going to finish teaching by 15th of March, whereas the exam is starting on the 5th of March. They don't speak to each other and say when are we going to be revising these things. But according to the ATP, their teaching time is overlapping and hitting the exam time. ... Let alone that we have learners that need to be told like twice ... I shall reteach it and if I'm reteaching, it means I'm extending time ... So, we end up not making revisions, taking them to exam questions like we are saying read K53*

Similarly, Participant 6 added the following:

*ATP is too broad ... the way they do ATP in mathematics is not fair. So, we have to cover ATP even the day before examinations.*

Participants 2 and 6 also mentioned the misaligned timeframes of the ATP and exam schedules. The participants suggested that the two are out of sync, which indicates a lack of communication and planning between departments. The overlap leaves almost no room for revision, which makes it not even viable to consider adding ESD integration. Furthermore, the participants' remarks about policymakers "not caring" and "not being fair" suggest that policymakers are disconnected from the realities on the ground. If ESD is to be integrated, the endeavour must be thoughtful and include significant restructuring and content reduction, and proper alignment with assessment priorities. Otherwise, it would be unrealistic. It is no surprise that teachers are opting for what they call the "traditional way of teaching" which is teacher-centred with a strong focus on memorising content for the exam, with very little effort to foster critical thinking and problem solving. Here, Participant 5 added the following:

*So, it means that if I teach measurement, I have to kind of bring in some concepts that work in carpentry to make this applicable in real life. But the way the curriculum is structured right now does not allow that. So, obviously, there must be changes, but careful changes if maybe the people who are curriculum deciders decide to integrate it with or relate it with real-life problems.*

The participants suggested that ESD integration could succeed provided that the curriculum is aligned with real-world applications that learners can relate to. Currently, the CAPS document encourages the use of real-life data like national surveys from StatsSA (DoE, 2011), which suggests that the participants may not be that familiar with the CAPS document. Therefore, if teachers do not carefully go through policy documents, sustainability-aligned objectives stated in policy documents may not be fully implemented.

Policymakers need to make careful changes. These changes include aligning the ATP with ESD objectives on a variety of topics and reflecting on all assessments so that teachers are familiar with them. For example, Participant 1 was teaching measurements during the classroom observation. His lesson incorporated ESD elements and he used scenarios that learners are familiar with. The lesson was enjoyable. Figure 4.3 shows a snapshot of Participant 1's lesson plan.

**Lesson Plan: 29/10/2024**

**Topic: Measurements with African Rondavels or Huts**


**Grade: 10**

**Subject: Mathematics**

**Duration: 90 minutes**

**Lesson Objectives:**

1. **Understand and apply measurements:** Calculate perimeter, area, surface area, and volume.
2. **Connect mathematics to real-world contexts:** Use traditional African huts to explore these concepts.
3. **Integrate Sustainable Development Goals (SDGs):** Relate the lesson to SDGs such as Sustainable Cities and Communities (SDG 11) and Responsible Consumption and Production (SDG 12).



*Figure 4.3: Participant 1's Lesson Plan Snapshot*

This lesson plan shows specific SDGs that are aligned with the lesson. During the lesson, Participant 1 used several African structures with which learners are familiar. The learners could identify the geometric shapes and were able to participate in the lesson. Protection of indigenous cultures is one of the ESD determinants for the SADC

region (SADC, 2022) and this lesson delves into a discussion about some cultural artefacts that learners could relate to while teaching mathematical concepts. Lessons such as these promote cultural identity while also teaching mathematical concepts as per the ATP. Moreover, the lesson introduced students to cost-effective and locally available building methods that promote responsible consumption and production (SDG 12). Participant 4 expressed a noteworthy viewpoint on the benefits of ESD integration:

*And it's very difficult because a concept like this is already incorporated in Maths Lit. But if you offer learners, they don't see it. They don't see the value in being able to use mathematical concepts in solving real-life situations. So, it's difficult. It has to be a change of mind with the teachers while imparting the knowledge and getting the learners to see the value. At the moment, this one is difficult.*

Participant 4 acknowledged that real-life concepts are already a core component of Mathematical Literacy. However, learners do not seem to recognise the value of these applications, and the participant attributed this to the teachers' mindsets. Furthermore, this disconnect mirrors a broader challenge with ESD integration into mathematics. Like in Mathematical Literacy, ESD requires making abstract concepts tangible and relevant to real life (Ferguson et al., 2022). This means interventions in the form of Professional Development initiatives are required to strengthen teachers' ability to convey the value of sustainability-focused mathematics to learners. Moreover, the content taught may refer to real life but may still not be relevant to learners due to the social class to which they belong. The schools in this study are in a peri-urban area; therefore, the content should speak to the learners' context. This means teachers need to tailor their lesson examples to their learners' context, as seen in Participant 1's lesson. Participant 5 explained the following:

*I am also concerned that we are teaching for marks, and we have time limitations ... We want to get to a point where we have finished, and we are comfortable so that we can start revising. We are not really looking into teaching learners to relate this to real life. We're not really teaching learners on how they can use these concepts ... for the benefit of the environment and the benefit of most of their families so that maybe they can somehow turn this into a sort of a business or whatever. ... We are not even trying*

*to make it relatable because we just want learners to get marks. We have pressure ... If your learners are failing, what are you doing? So, you don't kind of open your mind and allow your learners to also open their minds into seeing how this is applicable in real life. ... It's just like, get marks, that's it.*

Participant 5 highlighted the strong focus on achieving certain grades which overshadows the goal of helping learners make connections between what they are learning and real life. This type of teaching disregards opportunities for learners to learn skills and concepts that could benefit them, their families and their communities in practical and economic ways, which is sustainable. The participant stated that some families do have businesses, and that these should be benefitting from what their children are studying at school. Currently, there is an increase in the number of tuckshops run by foreigners while many local tuckshops are shutting down due to competition (Lamb et al., 2019) which highlights the very fact that what learners were learning often could not help families that owned businesses. According to Participant 5, teachers are under constant pressure to “finish” the syllabus, prepare learners for exams, and produce certain results. When teachers are judged based on these results, this creates a rigid environment with very little room for innovative teaching that makes mathematics more relevant to real life. In such an environment, ESD integration will most likely be deprioritised. This systemic focus is on marks and syllabus clashes with the goals of ESD, which is to promote problem-solving, critical thinking and sustainability (Teise & Le Roux, 2016). Participant 5 added the following:

*Others are builders ... They could teach them how to measure. Like when you are buying material, you need to know I need such and such material. Don't under- or overbuy.*

This highlights a practical way in which mathematics with ESD integrated can help solve real-life problems. Participant 5's comment confirms the value of Participant 1's lesson on measurements (making better purchasing choices based on proper calculations). However, Participant 5 stated earlier that teachers are not even trying to make mathematics relevant to learners' lives as their mission is to finish the syllabus and get learners to pass. For such beliefs to change, teachers need to be exposed to new experiences that challenge their deeply held assumptions and that encourage them to

contemplate a new way of teaching (Nerstrom, 2014). Participant 8 commented as follows:

*I think it will change learners' attitude since learners make maths so hard. If we use real-life situations, I think it will change their attitude towards it.*

Similar sentiments were shared by Participant 7:

*Yeah, it should be their perception of mathematics because they deem it as a difficult one. If we change the experience around them then I think it will change their perception around the subject as a whole.*

Participants 7 and 8 both recognised that many learners perceive mathematics as difficult and suggested that making it more relevant to their lives may make mathematics more relatable and less intimidating (Benson-O'Connor et al., 2019). This suggests ESD integration. Some participants (1, 2, 3, and 4) pointed out that policy is not clear on how sustainability concepts can be integrated while some participants (7 and 8) have never come across anything that seeks to promote ESD integration or sustainability. Participant 6 shared the following:

*In my opinion, this will be integrated with financial maths because financial maths is about real life when we are talking about the investment. It is something that you invest, and you will get in future. The learners can see that when they put in an interest and then if you are investing maybe R100,000, then in 10 years' time it will be R200,000.*

Participant 6's comment highlights the strong connection between ESD and financial mathematics, particularly in terms of real-life applications. The response suggests that financial mathematics serves as an effective entry point for the integration of ESD principles, as it deals with long-term investment, sustainability, and future financial planning. Participant 5 shared the following in this regard:

*CAPS policy for mathematics as it was mentioned before that CAPS document has bits and parts where it promotes sustainable goals. But when you come to the ATP, that's a different story. It's like just two different people looking at the same document.*

Participant 5 was alluding to the fact that the CAPS document does refer to sustainability aligned with broader educational goals like ESD. However, the ATP (which dictates the day-to-day execution of the curriculum) does not reflect the same. This suggests a misalignment between the aspirational goals of CAPS and the practical guidelines of the ATP. Furthermore, the metaphor of “two different people looking at the same document” points to a lack of cohesion in how the curriculum is designed and communicated across different levels. Noteworthy, while the CAPS document does not explicitly promote ESD integration, some ESD determinants can be found. For example, one of the aims of mathematics is to develop critical awareness of how mathematical relationships are used in social, environmental, economic and cultural relations (DoE, 2011). This, in a nutshell, suggests mathematics that is relevant to one’s life.

These findings underscore how systemic constraints, such as rigid ATP structures, policy misalignments, and inadequate support mechanisms, hinder teachers’ capacity to integrate ESD effectively. Msafiri’s ICT Integration Framework offers strategic insights into addressing these challenges by emphasising institutional support, flexible curriculum planning, and provision of appropriate ICT tools to ease teachers’ workloads and enhance lesson relevance. Simultaneously, Nerstrom’s Transformative Learning Model highlights the importance of disrupting entrenched teaching traditions and fostering critical reflection among teachers. By situating professional development within these frameworks, there is an opportunity to empower teachers to shift from syllabus-driven practices to learner-centred, sustainability-oriented mathematics education

### **4.3. ICT INTEGRATION IN MATHEMATICS TEACHING**

This section presents teachers' experiences of ICT integration into mathematics teaching. Educators should integrate ICT tools into teaching and learning to enhance learners’ learning outcomes, foster motivation, increase engagement, and promote skill development (Msafiri et al., 2023). However, the data suggested that teachers are not adequately exposed to ICT tools and that those who have been exposed to ICT tools have found them to be of little use. From the FGD, it appeared that the main ICT tools

that teachers made use of was data projectors and laptops. When the participants were asked if they are using ICT in their math lessons, Participant 2 shared the following:

*I use it when I'm doing revision because when we are revising instead of printing many are pushing paper. I just display a question and give them time and they answer it. To not deviate, I just project it here and then we answer it here.*

Participant 2 used the projector for display purposes with the primary focus being revision. This resource is clearly under-utilised since it can also be used for simulations, interactive problem-solving activities and interactive games like Kahoot and Blooket. In this case, ICT is not being used to facilitate ESD integration. Instead, ICT is used for visualisation according to Participants 2, 4 and 5.

GeoGebra and Kahoot offer notable pedagogical advantages that align well with ESD principles. GeoGebra enables learners to dynamically explore mathematical relationships, fostering inquiry-based learning and supporting students in modelling real-world sustainability scenarios such as resource distribution or environmental changes. Its interactive visualisation tools encourage learners to test hypotheses, develop critical thinking skills, and engage with mathematics in meaningful contexts. Similarly, Kahoot supports gamified learning that makes lessons more participatory and engaging. By incorporating quizzes and interactive challenges on sustainability themes, Kahoot promotes collaboration, reflection, and deeper understanding among learners. These tools not only enhance engagement but also create opportunities for transformative learning, allowing students to connect mathematical knowledge to global and local sustainability issues.

While Participants 4, 5 and 7 opted to no longer participate in the study, Participants 1, 2, 3, 6 and 8 participated in the Professional Development session organised by the researcher. Here, they were exposed to several ICT tools that they could incorporate in their lessons. However, during the classroom observation, Participant 2 was still using the projector strictly for displaying the lesson presentation. The learners did not use any ICT tools. Participant 1, on the other hand, appeared to be using ICT for more than visualisation:

*For ICT, I use this to visualise with kids and, um, especially in topics that involve graphs. Always teach them about the graph shift which you see shifting to the left or to the right downward, and when it comes to demonstration as well simulations that show how the graph is moving, how the object is moving such as the ball, we can see a particular ratio.*

Here, Participant 1 was using the projector and the laptop as main ICT tools in the lesson. Like Participant 2, it seemed that Participant 1's intent was not to promote ESD but merely to display content to the learners. Here, ICT was used to encourage problem solving and critical thinking around sustainability issues. During the classroom observation, the participant used OneNote, Geometer's Sketchpad 5 (GSP5) and Google Photos in one lesson. He also had a handheld device on which he wrote while moving around the class, offering support. OneNote allowed the teacher to make drawings and notes while GSP5 was used to draw accurate geometric shapes. Google Photos was used to obtain high-quality photos of African huts or rondavels.

In this lesson, ICT was used to facilitate ESD integration into the lesson. The teacher was able to engage students in discussions around sustainability practices when building structures. The lesson promoted an understanding of traditional architecture, which often incorporates eco-friendly materials and sustainable construction principles (e.g., the rondavels are made from natural resources like mud, thatch, and wood). Furthermore, the lesson linked mathematical concepts (such as area, volume, and surface area) with real-world applications that emphasise sustainable building practices. This made the lesson interesting. However, the learners did not use any technology during this lesson. While there were no devices for the learners to use, the teacher could have used online resources like Kahoot and Blooket for interactive activities which can be projected onto a screen. However, this exercise would have required the teacher to buy data bundles since School A has no internet. During the post-observation interview, Participant 1 stated the following:

*I wish I had a wi-fi or sufficient data bundles to show learners more pictures of huts.*

This comment implies that integrating online ICT tools in lessons is not something that the participant will employ consistently due to the unfair financial burden that comes

with this practice. It appears that when the participants in this study think of ICT integration, it means being able to display data on a screen through a projector. There is very little effort to get learners to use ICT tools during the lesson, which could entail using the internet to search for more information about sustainability issues. The teachers only used ICT for visualisation. Even after the training that exposed them to various online ICT resources, the classroom observations showed that, where ICT was used, this was done for visualisation.

This predominant focus on visualization, while beneficial for illustrating mathematical concepts, raises important questions about its alignment with the transformative goals of ESD and the extent to which it engages learners in critical and participatory learning processes. While the use of ICT for visualization can enhance learners' conceptual understanding by making abstract mathematical ideas more concrete, this practice alone does not fully align with the broader objectives of Education for Sustainable Development (ESD). Visualization supports comprehension of complex systems and can be a useful entry point for integrating sustainability concepts. However, if learners are not actively engaging with the material, this approach risks reinforcing passive learning and limiting opportunities for deeper inquiry. ESD emphasises participatory and learner-centred pedagogies that cultivate critical thinking, problem-solving, and collaborative decision-making skills. These capacities are essential for addressing real-world sustainability challenges. When ICT is used only as a display tool, it reduces opportunities for dialogue, reflection, and meaningful interaction with sustainability issues. A shift toward participatory methods, where learners engage with ICT interactively to explore local and global challenges, is therefore critical for fostering engagement and empowering students to become active contributors to sustainable futures. However, at this stage, there were clear intent to promote ESD.

While Participants 6 and 8 opted to participate in the classroom observation phase, Participants 1, 2 and 3 were observed. During the post observation interviews, the participants were asked the following question, “Describe how you incorporated ICT tools to facilitate the integration of ESD principles in this lesson”. While Participant 3 did not use ICT due to renovations, Participant 1 shared the following:

*I used various ICT tools such OneNote for Windows and simulation software like GSP5. These tools allowed learners to visualise mathematical concepts*

*related to measurements in real-world contexts, such as drawing and calculating the area for sustainable housing or understanding resource distribution in rural and urban planning. Additionally, Google Photos were used to show learners how African rondavels or huts [uguqa in IsiZulu] look like and encouraging them to relate mathematical concepts to real-world applications.*

Similarly, Participant 2 responded as follows:

*I used projector and smartphone to demonstrate the meaning and behaviour of rotational frequency in tech maths against the real world more especially in cars. I downloaded the pictures of the cars with the stickers of their speed limit at the backside of them. While projecting, I also displayed the fastest cars and their top speeds ... We then extended the meaning of the speed to rotational frequency in order to see how fast those fast cars in km/h are and checked if they can be used where there are people, cows and also the level of burning fuel.*

In both instances, ICT was used for visualisation purposes. This underscores the need for more consistent Professional Development so that the few resources available are optimally used which will ultimately improve the learning experiences of learners in mathematics classes. However, both in lessons, ICT was used to also facilitate discussion around sustainability issues. During the post-observation interviews, all three participants were asked to describe the impact of ICT on learners' understanding of the connection between mathematical concepts and real-world sustainability issues. The participants shared the following:

**Participant 1:** *The use of ICT significantly enhanced learners' understanding of the connection between mathematics concepts and real-world sustainability issues. By engaging with simulations, learners observed the immediate impact of mathematical calculations on environmental issues, such as the material that need to be used to build rondavels or African huts. This not only made the mathematics more relevant but also fostered critical thinking as they analysed data related to sustainability. The ability to visualise problems in a digital format helped them grasp complex concepts more effectively.*

**Participant 2:** *ICT made it very simple for learners to see what we were talking about. It was easy for the learners to relate the concept(s). The main part that made ICT to have more impact is the fact that everything comes to one screen. Calculations and handwriting work is done in that one screen such that a child cannot be tempted to lose focus while looking for calculators or make mistakes in calculations. But with ICT every tool is on the display.*

**Participant 3:** *Well, ICT, I believe it provides visualisation, and it helps, or it allows the learner to be able to relate and see how mathematical concepts can be used in the real world. So, resolving problems, it helps them to put into practical use mathematical concepts that they have learnt in class.*

All three participants emphasised the use of ICT primarily for visualisation. This means that whatever resources they had at their disposal, these were most likely underutilised. Yet, they are praising ICT for its ability to allow learners to see how mathematical concepts are linked to real-world problems.

Over and above using a projector, Participant 5 made use of online ICT resources like Desmos. He shared the following during the FGD:

*Well, mainly I focus on Paper 2. So, in Paper 2, the main graphs are trigonometric graphs. Okay, so normally if I teach, I'd sketch the graphs on the board first just to give them the basic idea. Then when the graphs get a little bit more complicated, maybe there's a sheet that ... maybe there is a change in amplitudes over graphs, especially in trigonometric graphs because they are tedious to draw. So, I would use a computer. There are programs on the internet that I normally use. And one is called Desmos.*

Participant 5 was the only participant who made use of Desmos. According to him, to a limited extent, the learners were able to use Desmos on their cell phones. However, the challenge was access to data bundles. Participant 5 explained:

*Technology is there, right? But it's how we get access to it, that is a problem. Because for instance, I have my own laptop. The school has a data projector, and learners have the cell phones. You can actually ask them because at some*

*point I ask grade 10s to come with their cell phones. But the problem is they come with their cell phones but don't have access to data because they need to buy data.*

The use of cell phones appeared to be a common practice as it was mentioned by Participant 5 from School B, Participant 2 from School A, and Participants 7 and 8 from School C. It seemed that the participants had to cope with a severe lack of ICT tools. Therefore, to bring ICT into the classroom, they requested learners to bring their cell phones to school. Participant 7 said the following in this context:

*I used a cell phone, but some learners do not have cell phones. So, it's challenging for the learners. So, I have to group them using one phone ... So, it's not easy to work with this.*

Participant 6 added the following:

*Sometimes you use the cell phones like asking learners to go on the internet to find the right information.*

It was clear that the teachers were facing several challenges forcing them to be innovative in order to provide better mathematical experiences. Some challenges were linked to resources, while some were linked to lack of clear direction and support from the Department of Basic Education. Challenges such as these can result in poor ICT integration and prevent some participants (like Participant 4) from using ICT in their mathematics lessons. Participant 4, who had 23 years of experience, became more comfortable teaching without ICT. While the teachers' efforts to integrate ICT are commendable, it is worth noting that these efforts were not intended to facilitate sustainability-focused activities but rather to use Desmos (Participant 5) and to search for question papers (Participant 8). Participant 4 commented as follows:

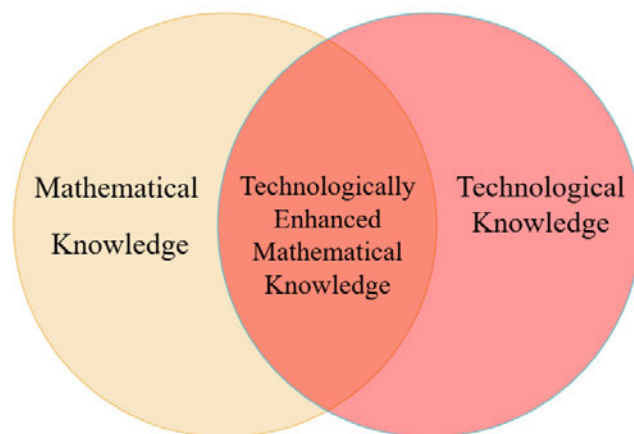
*I attended the same course with him where we were taught GeoGebra. I came back and I used it quite extensively. I think I stopped around 2014; I don't know why I stopped. And now that just struck a nerve.*

Here, the participant admitted to stop using GeoGebra without a clear reason. This raises questions about barriers to sustain ICT integration which may include lack of

support, time constraints and curriculum pressure, lack of encouragement, and lack of follow-up.

The data generated from the FGDs suggested that some teachers in peri-urban schools are unintentionally integrating some ESD into their teaching of mathematics. The FGD data also suggested that some of these teachers are making some use of ICT in their mathematics teaching. However, there were no deliberate efforts by these teachers to use ICT to facilitate ESD integration in mathematics. The intentional use of ICT to facilitate ESD integration was only seen after the Professional Development session offered by the researcher in this study.

The teachers from the peri-urban schools clearly lacked knowledge pertaining to the intersection of mathematics and ICT. Their use of ICT was limited. Their lack of technologically enhanced mathematical knowledge means that they need upskilling to improve, transform or deepen their understanding of mathematical concepts and practices through the use of digital tools and technologies. Figure 5.2 shows the intersection of mathematical knowledge with technological knowledge, which should become a stronger focus in education.



*Figure 4.4: Intersection of Mathematical Knowledge and Technological Knowledge  
(Source: Author's own illustration)*

While the teachers in this study demonstrated some progress with ICT integration, which is essential for ESD integration, they had to cope with several school-based or external challenges, as explained below.

### 4.3.1 School-based challenges

This subtheme or pattern presents participant accounts highlighting challenges in the school environment that hindered the effective use of ICT to facilitate ESD integration. Participant 3, who did not use ICT in her lessons, observed:

*The school has an ICT sector, but it is not effective. The school has an ICT class, but it's not effective. ... Then the school has a tablet which it's just for one teacher, and then you're supposed to use the ICT and just rotate ... Then they used to have ... tablets that were donated by some company. But those tablets were only for a specific, specific math thing, you know, that uh [Siyafunda program]. ... We ended up not using them, but we had those only for that specific [Siyavula] thing.*

Siyafunda CTC is a non-profit organisation that focuses on empowering communities by providing access to digital technologies and essential skills. The researcher in this study used to be a teacher at School A and was still a teacher at the school when the tablets were donated.

Participant 3 highlighted several challenges at School A: (1) Despite having an ICT class and donated tablets, the school lacked the infrastructure and systems to make ICT resources accessible and effective for regular use; (2) access and time constraints meant that ICT tools, which could significantly enhance learning, remained underutilised; and (3) programs like Siyafunda, designed to support math learning, were not fully leveraged due to logistical barriers which the school management team should be focusing on.

Such challenges were also evident during the observation. Participant 3 did not use any ICT during her lesson. The classroom she used had no electricity due to theft, which was the case for most classrooms at the school. While the lesson itself integrated ESD, the teacher was not able to leverage ICT capability. Participant 3's comment depicts School A as an environment where it is challenging to use ICT to effectively facilitate ESD integration. Importantly, while Participant 3 did not use ICT during the lesson, she had a typed lesson plan with clear objectives aligned with appropriate SDGs. This showed that ICT was used during the planning phase of the lesson intended to integrate

ESD. This means that teachers from poorly resourced schools can still use the limited ICT resources to plan ESD-focused lesson plans leveraging ICT in their practices.

During the post-observation interview, Participant 3 was asked the following question: Describe how you incorporated ICT tools to facilitate the integration of Education for Sustainable Development (ESD) principles in this lesson? She responded in the following way:

*Okay, well, with our schools, they have renovations at hand. So, it was difficult for me to get the IT room. So, I ended up using a normal classroom, which is normal teaching the old way that we do. But I would have used the spreadsheet. The spreadsheet would help learners visualise relationships between the principle, the rates, the time and interest. So, I could have also tried a game in Kahoot as you guys showed this, but I couldn't use the ICT ...*

Participant 3's school has over 40 teachers and one IT room. It is no surprise that Participant 3 was not able to secure the room regardless of renovations. The lack of ICT facilities became a missed opportunity for learners to get an enhanced learning experience. Also, the participant's remarks about "normal teaching" highlighted the fact that ICT integration is still an elusive goal for them. During the Professional Development offered by the researcher, the participants were introduced to a new way of teaching mathematics (one that integrates ESD through ICT). This challenged their deeply held assumptions. If the environment is not conducive to ICT integration, teachers tend to go back to their "normal way" of teaching which lacks innovative practices and which is one of the pillars of ESD (UNESCO, 2022). Here, Participant 5 commented as follows:

*We don't have wi-fi. But if we had access to wi-fi, it would be easy... Travelling to class with the laptop and the data projector takes time to do a set up ... The lesson is one hour, and we want to cover the lesson within 20 minutes to allow some time for class work and see whether they understood the lesson. But then the time it takes, the easiness, the flexibility to allow technology to be used consistently, that's where we lack in terms of technology because we find it hard to do the same thing over and over again. You can't be doing the setup Monday to Thursday or every day and everything.*

Participant 5 (from School B) also highlighted the inadequate infrastructural support for the seamless integration of technology in classrooms. Overall, 62.5% (5 out of 8) of participants reported limited access to ICT resources like laptops or projectors, and 75% (6 out of 8) cited time constraints as a barrier to consistent ICT use in their teaching. With only an hour for a lesson, of which 20 minutes are allocated for direct teaching, the time spent on ICT setup detracted from instructional time. This puts pressure on teachers to balance technology use with covering essential content and leaving time for learner engagement and practice.

Participant 2's classroom observation confirmed these challenges. Participant 2 spent over 20 minutes trying to setup the projector while the learners were not engaged in any tasks. Consequently, the participant was unable to finish the lesson on time. Importantly, this lesson was also ESD focused and integrating ESD was not the reason the lesson was not completed in time. Therefore, it is only with proper ICT infrastructure that teachers will be able to effectively use ICT to facilitate ESD integration in mathematics lessons. During the post-observation interview, Participant 2 had the following to say about challenges he faced in the lesson:

*Lesson planning was not hard since it was explained to us and also got some training and examples on how to plan a lesson that also integrate the ICT and ESDs. Time management was very bad in the practical part of the lesson because my PC was very slow. It consumed a lot of time even to start up. Since we are a school that is not well resourced, I had no choice but to set up the projecting system exactly at the time we were supposed to be starting with a lesson. Then system connection and some app delays resulted in a bad time management.*

Participant 2 used ICT during the planning stage of the ESD-focused lesson. Regardless of the challenges experienced by the teacher during the lesson, ICT was still used to deliver this ESD-focused class. The technical issues experienced by Participant 2 could have been avoided if the classroom already had a well-maintained ICT set-up. For ICT integration to be effective, leadership needs to provide and maintain ICT resources (Msafiri et al., 2023). In this lesson, it was only the projector and the tablet that belonged

to the school. The laptop belonged to the participant. More investment in ICT infrastructure is clearly needed as this will allow teachers to spend less time on set-up and more time on effectively teaching their ESD-focused lessons with the aid of ICT. Participant 7 shared the following during the FGD regarding hindrances preventing the effective use of ICT in math lessons:

*The inadequacy of resources and it's also time-consuming because you have to prepare the whole lesson for the practical part ... Those are the two challenges – the inadequacy of resources and it is also time-consuming.*

Participant 7's comment underscored the lack of ICT resources at School C. The participant found it time-consuming to prepare for a class that required ICT equipment. If the school had ICT-equipped classrooms, the teachers would find it less time-consuming to integrate ICT. In short, facilitating ESD integration through ICT is a challenge for mathematics teachers at School C as the environment is simply not conducive to ESD integration through ICT.

When the researcher asked the participants about the reason for the lack of ICT infrastructure, Participant 4 shared the following:

*Things get lost in schools. If the department brings laptops or computers, they get stolen ...*

This points to a lack of adequate security measures to protect valuable ICT resources such as laptops and computers at School B. This could discourage schools from investing in ICT equipment. The issue of theft, as mentioned by various participants, may also reflect broader socioeconomic issues in communities. This comment suggests that, for ESD to be effectively facilitated through ICT, it would require school management to look into the issue of security for their ICT infrastructure. Participant 7, from School C, also made a link between lack of adequate security and lack of ICT infrastructure:

*Yeah, I think so because a lot happens around the school. It does affect the level of resources in school.*

The participants from School C were reluctant to talk about security concerns at the school. However, the comment above does imply that security is inadequate, which ultimately means inadequate ICT tools to facilitate ESD integration in mathematics classes. Again, this highlights the socioeconomic issues faced by the community. The researcher spent five years at School C as a high school learner. During that time, most classrooms had no power and no ICT was used by teachers and learners but there were still cases of theft of other school equipment. Furthermore, the researcher spent six years at School A teaching information technology and mathematics. The school had computers donated, but these too were stolen on several occasions. School B is a girls-only school in the area where the researcher lives. School B had a computer literacy subject. The school also suffered loss of computers due to theft. Therefore, the issue of theft of ICT infrastructure requires attention as this ultimately affects teachers' ability to facilitate ESD integration through ICT.

These infrastructural challenges have significant pedagogical implications. When ICT resources are scarce or unreliable, teachers are often forced to rely on traditional, teacher-centred approaches that limit opportunities for inquiry, collaboration, and critical thinking. Such methods run counter to ESD principles, which prioritise participatory and experiential learning. For instance, without access to dynamic tools like GeoGebra or online sustainability datasets, learners miss out on engaging with real-world problems in a meaningful way. The lack of reliable internet and security measures further discourages teachers from experimenting with ICT-based strategies that could stimulate learner agency and promote problem-solving skills. Consequently, these systemic constraints not only impede the integration of ESD but also reinforce an educational environment where learners are passive recipients of knowledge rather than active participants in constructing sustainable solutions. Addressing these barriers is essential to unlock the transformative potential of ICT in fostering critical and engaged citizens.

Participant 4 made this comment:

*I think a few years back we had [Siyafunda]. There were tablets where learners would be able to do different problems there. But the issue was ... our learners, they'll be fixated on the gadget other than on what should be learned.*

Participant 4 highlighted a different yet critical issue where learners become more occupied with the gadget itself rather than with the educational content it provides. This suggests a gap in how ICT tools are managed and integrated into the classroom and the absence of a learning culture that incorporates ICT tools. This also requires teachers to take advantage of learners' enthusiasm with devices and introduce fun educational interactive applications like Kahoot and Blooket. This way, both teachers and learners can use ICT tools as opposed to the current status quo. This also presents an opportunity to use the available ICT tools to engage learners in sustainability issues as this content is readily available on the internet. However, all of these require stable internet connection. All the schools in this study did not have internet connectivity, which meant that the teachers carried the burden to sponsor activities that required internet access. This is another setback in the quest to effectively integrate ESD into mathematics through ICT. However, the teachers here still have an option to use offline resources. The teachers can find videos online on sustainability issues that relates to targeted mathematical concepts. These can then be shared via offline methods (cables or Bluetooth) to student devices. Whatever ICT tools are available, there is potential to leverage them to facilitate ESD integration. Participant 5 made the following comment:

*If we had wi-fi, something would motivate me to have a laptop because it would be useful. Something would motivate me to have a projector. Something would motivate me to go and look for apps, which are actually promoting mathematical modelling using technology to teach mathematical modelling. So, those resources – laptop, data projector, white board that we use for projecting. But because we use our own resources from our own pockets, you can find that we don't pay attention at all or sometimes. We won't even consider it because if, for instance, I have a laptop, if it falls on the floor... and it cracks, no one will pay... but I will get a sorry, that's all. And that will be the end of it.*

Participant 5's comment suggests that lack of basic infrastructure demotivated the teachers in this study to invest in ICT tools or explore technology-based teaching methods. This means, in this environment, even if ESD was integrated into mathematics lessons, ICT would not be leveraged to improve or facilitate this integration. Furthermore, spending from their own pockets emphasises their commitment to provide technologically enhanced learning experiences to their learners. This also points to the

potential for teachers to commit to using ICT to facilitate ESD integration. However, this puts an unfair financial burden on teachers since they are not claiming these expenses back. The school and the department at large have teachers willing to go the extra mile to provide high-quality teaching even with limited support from stakeholders such as the department. Moreover, teachers are using their own devices while carrying the risk of damage or theft for which they will not be reimbursed.

Technology was used in two of the three lessons that were observed. The teachers were using their own devices, and the internet was only used during the planning stage of the lessons. However, lessons were still ESD focused and fostered critical thinking on sustainability issues. Therefore, even in environments where ICT tools are limited, the ICT tools available can still be used to promote ESD values. Participant 4 made the following comment:

*On top of what Participant 5 said, accessibility also. You know, even if you do use our own things, if you have to carry them to and from class which becomes a problem. You know, a room where you know it's a multi-purpose room or it's a room where learners sit, are they able to view these things without you having to move them? If you can go into a room and have a smartboard and have a data projector there available. Maybe what you do, you bring a USB or whatever you have.*

Participant 4 again highlighted the logistical challenge of having to carry ICT equipment to and from class. This absence of readily available ICT infrastructure in schools demotivates teachers to regularly use technology. Leadership needs to provide an environment with well-maintained ICT infrastructure (among other things) since ICT integration also depends on teacher motivation (Msafiri et al., 2023). Here, the participants painted a picture of an ideal environment where classrooms have fixed ICT setups, such as smartboards and data projectors, and where teachers only need to bring a flash drive or other data-storage device. All the other participants were nodding in agreement with Participant 4's comment. Such a setup could have saved Participant 2 the 20 minutes lost because of equipment set-up at the start of the class – valuable time that could have been used to add depth to the content being taught. Fixed setups like smartboards and projectors can help to ensure seamless lesson transitions, allowing

more time for interactive learning and inquiry-based discussions – key components of ESD. Participant 1 added the following:

*But the main thing about this ICT is that it caters for kids who are rich and who have data ... Remember during Covid, we were doing online teaching and learning. So, there was no chance that kids can come to class. They were using technology. Then there is something which I'm using right now, which is OneNote. OneNote you can share your notes or your examples or calculation with learners. Then you can view it at home. If kids don't have data, then it becomes so limited. Sometimes it depends on the environment.*

Participant 1 pointed out a major barrier to ICT integration – the divide between learners who have access to data and devices and those who do not. This highlights how socioeconomic factors can create disparities in educational opportunities, making the participant believe that ICT is meant for a certain group of people which may demotivate teachers to use ICT tools. If teachers view ICT as inaccessible to all learners, they may default to traditional teaching methods, limiting innovative problem-solving approaches that could foster sustainability awareness in mathematics. Furthermore, the reliance on data and devices for remote learning excludes learners from lower-income backgrounds who are unable to afford these resources. This creates a gap in access to education and potentially widens existing inequities. Learners who lack access to data and devices are excluded from these interactive learning experiences. This undermines inclusivity and equal opportunities, which are core principles of ESD. Participant 4 mentioned the following in this regard:

*I would think that the most prominent challenge is time ... Because we teach for marks and we teach mainly for, if I can put it in, I don't know, most unpopular submissions, and once you finish you submit ... So, the time to incorporate and get whatever tools you need so you can use in your teaching. You might do it once in a while, but after that you realise this is taking too much of my time. And you just want to hurry and finish it.*

Participant 5 once again referred to the marks-centric approach where the focus is on finishing the syllabus, leaving very little room for innovative teaching through ICT that promotes ESD integration. Incorporating ICT tools into lessons often requires

additional preparation, setup, and explanation time. In their case, it included moving equipment. Participant 4 implied that these demands are in conflict with the need to cover the curriculum within rigid timelines. The phrase “unpopular submissions” likely points to administrative requirements, such as lesson planning and reporting, which are time-consuming and detract from teaching innovation. Teachers may feel forced to prioritise paperwork over creative ESD lesson planning, which limits their ability to integrate interactive and meaningful sustainability-related tasks. Hence, the teaching environment appears not to be conducive to effective ICT integration.

The issue of time was also evident in all classroom observations in that none of the participants could not finish the lesson on time regardless of whether ICT was used. For all the participants observed, there were no learning targets on the board, no success criteria, and no exit ticket. Clearly, these are not a priority since teachers feel that they need to “hurry and finish”. The absence of learning targets and exit tickets suggests that lesson objectives are not explicitly communicated. In ESD, clear goals are essential for fostering student agency, reflection, and real-world problem-solving.

During the post-observation interviews, teachers were asked (individually) the following question: “*What challenges did you face in, lesson planning, managing time and addressing diverse learner needs while integrating ICT for ESD in the lesson?*” This is how Participant 1 voiced his opinion:

*I had a problem knowing which ICT tools to use. That is a challenge. Then, what else was a challenge with the getting questions that would cater for diverse needs? Because we got learners that are bright and sharp and then we got slow learners. So, there was a problem. That was a challenge. And then getting more info on the loans, the investments as well as the repo rates ...*

Participant 1 had issues with time management due to having to reteach formulae and Participant 2 had time management issues due to technical issues while Participant 3 did not use any ICT tools to facilitate ESD integration during her lessons. If the school had internet connectivity, the teachers would have been able to use AI to determine suitable ICT tools to facilitate ESD integration, generate content (on sustainability issues) tailored to the different cognitive levels of the learners, and find more information on required content that speaks to sustainability practices. It is worth noting

that the lesson was observed after a training session which included a segment on ICT tools available to facilitate ESD integration in their math lessons. This underscores a need for follow-up and continuous Professional Development, a practice that is lacking on the department's side.

#### 4.3.2 Other Challenges

The challenges that hindered ICT use went far beyond the classroom and the school. Data suggests that the department or policymakers have not given clear direction on how ICT could be integrated nor do they provide adequate resources and training to achieve this integration. Without a policy-driven ICT integration framework communicated to teachers, teachers are left to figure out ICT use on their own, leading to inconsistent and fragmented approaches to ESD in mathematics. Some schools or teachers may attempt to integrate sustainability concepts through technology while others avoid it altogether due to lack of support. For example, one teacher may use data visualisation software to teach learners about climate trends while another avoids ICT due lack of clear guidelines or access.

The participants were asked if there is any directive from their curriculum documents, like the Annual Teaching Plan, that suggests any ICT tools they can use in their lessons. This was Participant's 2 response:

*... they don't give us something like tools that we can use for that topic, such as Sketchpad ... I think they're trying to cater for those who are not the same. So, if you maybe suggest that the schools must use maybe Sketchpad – some teachers, they don't have electricity in their schools. Some, they don't have laptops and don't have desktops. I think they are thinking about that. I don't know, but I've never seen any such a scheme on the ATP.*

Participant 2's comment suggests a gap in the curriculum as it relates to the integration of ICT tools into mathematics teaching. This leaves teachers to identify tools independently, which may create inconsistency in teaching methods. Pedagogical understanding is a critical exponent in ICT integration (Msafiri et al., 2023). Individual teachers will choose different tools and approaches, leading to inconsistent learning experiences across schools and classrooms. Some teachers may effectively integrate

sustainability-focused ICT tools while others may ignore them altogether due to lack of familiarity. This is how Participant 3 commented on the topic:

*There's nothing on the curriculum document itself but the district tries to take the teachers and then they send them to some place so that they go and learn some skills ... So, the department does have a set of projects, but there's nothing on the ATP that states that or stipulates that.*

Participant 3 pointed out that the curriculum document lacks explicit references to or directives for integrating ICT or other innovative teaching practices. A significant 87.5% (7 out of 8) of participants identified infrastructural barriers (e.g., lack of Wi-Fi, limited devices) as key obstacles, and 50% (4 out of 8) also cited insufficient administrative support. This omission leaves teachers without a clear mandate or structured framework to follow. The absence of such guidance in the curriculum means that valuable initiatives, such as ESD integration through ICT, may not be systematically or consistently implemented across schools. The district's initiative to provide teachers with skills training, such as those offered at Hilton College, reflects an acknowledgment of the gaps in the formal curriculum. Without curriculum-based directives, teachers interpret ESD integration through ICT differently, leading to disparities in teaching approaches. Some educators may actively incorporate digital tools to explore sustainability-focused math topics while others may avoid them due to the lack of an official requirement.

The data suggests that there have been efforts from the department and third-party organisations to provide ICT-related training for teachers which could potentially help to facilitate ESD integration. However, these were met by some challenges as well.

#### **4.4. PROFESSIONAL DEVELOPMENT FOR TEACHERS**

ICT integration depends on Professional Development to prepare teachers to harness technological knowledge and pedagogical understanding with the support of stakeholders in an environment conducive to such learning (Msafiri et al., 2023). Various such initiatives have been offered by the Department of Basic Education and some third-party organisations. Often, these efforts were not followed up, which means teachers were not fully implementing what they have been trained on.

The professional development initiatives mentioned by participants reflect a fragmented and inconsistent approach to teacher support for ICT and ESD integration. For instance, SADTU's workshops included sessions on mathematical modelling and exposure to robotics, yet participants indicated that these were one-off events with little follow-up or support for classroom implementation. Similarly, Vodacom offered ICT-focused training, but its content was not tailored to the integration of sustainability themes within mathematics lessons. The Fundisa for Change program provided teachers with learner-centred strategies for ESD, yet its limited duration meant that only one in five participants reported significant changes in their teaching practices. These examples suggest that while programs exist, their infrequency and lack of alignment with teachers' specific contexts undermine their effectiveness. To support transformative teaching, PD initiatives should offer regular, sustained engagement, practical exemplars, and opportunities for reflection to address both technical skills and pedagogical mindsets required for ESD. Therefore, without ongoing support and monitoring, teachers fail to fully integrate ICT tools into their mathematics lessons, which means ESD integration also suffers.

Some teachers may temporarily experiment with ICT while others abandon it altogether due to uncertainty about best practice. For example, a teacher trained on using data visualisation tools to teach sustainability-focused lessons may not continue using these tools if no post-training reinforcement occurs. Participant 4 is one such teacher who received training with no follow-up. As a result, he could not even recall the name of the application they were trained on.

The teachers were asked to think about the Professional Development they have received from either the Department of Basic Education or a third-party organisation, and whether any of these sessions focused on ICT use or ESD integration.

Participants 7 and 8 stated that they have never heard about these concepts during their Professional Development ("workshops" being the common term). Only 25% (2 out of 8) of teachers reported receiving professional development on ICT integration for ESD, while 75% (6 out of 8) had not attended such training. Their Professional Development sessions were just about content. Based on their experiences, teachers form assumptions which become their values and beliefs (Nerstrom, 2014). This notion is supported by recent studies highlighting the role of Professional Development in shaping teachers'

beliefs and instructional practices. For instance, Martinez et al. (2025) argue that teachers are less likely to adopt practices from professional development when these contradict their existing beliefs, highlighting the importance of aligning PD with teachers' belief systems from the outset. They further note that teachers' beliefs function as a filter through which new pedagogical practices are interpreted, mediating how such practices are taken up in the classroom. Similarly, Siyam et al. (2025) found that well-designed technology-focused professional development can strengthen teachers' self-efficacy, reshape their practices, and foster confidence in integrating ICT effectively in the classroom. Hunt et al. (2023) also emphasize that teachers' beliefs and practices are interdependent, suggesting that professional development which intentionally addresses both is more likely to result in sustained changes in classroom practice. Therefore, if teachers have never encountered ESD or ICT integration in their Professional Development sessions, they are unlikely to prioritise these and would rather continue teaching mathematics in a conventional, content-focused manner which they believe is what is expected by the Department of Basic Education. Consequently, they miss opportunities to meaningfully link mathematics with real-world sustainability challenges through the utilisation of ICT. Participant 3 responded as follows:

*... besides the department on its own, there is also something that was organised by [SADTU] where they call the teachers from different schools and then they are teaching them ... they were workshopping them towards this mathematical modelling and technology. They say it was inclusive of even... robotics, yes. ... They do want to implement. They do want to change, it's just that that's not going to happen overnight.*

Participant 3's comment points to an effort by the South African Democratic Teachers Union (SADTU) to modernise education and this is likely approved by the department since teachers are using teaching time to attend these events. However, the participants did not make use of any ICT tools during the lessons observed by the researcher. The lessons were very much teacher-centred with no ICT tools present. Also, the classrooms had no electricity due to cable theft. Furthermore, the expectation that trained teachers must return to their schools and train others places a significant burden on them given the challenges that teachers are facing which include time constraints, curriculum pressure to finish lessons, and lack of ICT infrastructure. This expectation is therefore

unrealistic. Even though teachers attend Professional Development sessions, their lack of ICT use in actual lessons suggests a failure to translate training into practice. This means that ICT-supported sustainability learning remains theoretical rather than applied. Furthermore, the absence of electricity due to cable theft highlights a major infrastructural challenge that prevents ICT integration. Even with teacher training, a lack of functional technology makes it impossible to implement digital tools for ESD-focused mathematics lessons. Participant 2 commented as follows:

*They do send us links and they said you attended this workshop ... online in Zoom. I think they assume that we all have access to internet from where we are. ... They protect themselves from those calls that we do not have these resources ... but like I say, I think the department is running away from doing those responsibilities. They don't even make a tracking form of some sort to these technologies. ... There must be tracking of the progress in terms of this because if you check the progress, it calls you to go to schools and see how they use it. If they don't have electricity, then you have to install electricity. So, I think that is why it will be a problem ... because there will be no progress.*

Participant 2's comment highlights frustration with systemic inefficiencies, inadequate support, and the lack of accountability in implementing Professional Development initiatives and ICT integration. Systemic inefficiencies, such as inadequate Professional Development and infrastructure, mean that teachers struggle to integrate sustainability concepts into their teaching. Without institutional backing, ICT-enabled ESD becomes a theoretical concept rather than a practical reality for schools in peri-urban areas. Moreover, the department's reliance on online workshops and tools, such as Zoom, assumes universal access to internet connectivity and devices which is clearly not the case in all three schools. This reliance on online Professional Development also confirms Participant 1's earlier comment that ICT is for the rich because in this case, teachers from well-resourced school were better positioned to benefit from such Professional Development opportunities. This prevents equitable ESD integration, as only well-resourced schools benefit from digital learning opportunities. Furthermore, teachers having to finance their online learning contradicts ESD's emphasis on equal opportunities for professional growth. This financial burden creates a divide, where only those who can afford data costs can benefit from ICT-based Professional

Development which could potentially accelerate ESD integration. Additionally, teachers in resource-poor schools (in peri-urban areas, for example) may be unable to access open-source educational tools that promote ESD concepts. As a result, mathematics teaching remains disconnected from sustainability topics, weakening students' ability to apply mathematical reasoning to real-world environmental and social challenges.

Participant 2 made this comment: “... *they don't say anything. They protect themselves from those calls that we do not have these resources ... but like I say, I think the department is running away from doing those responsibilities.*” This creates the perception that officials are avoiding addressing foundational problems, such as inadequate resources and infrastructure, and would rather protect themselves from scrutiny by keeping their distance. The department's reluctance to directly engage with schools and track ICT implementation progress contradicts ESD's emphasis on sustainable capacity-building (Olsson et al., 2022). Effective ESD requires consistent evaluation and adaptation (Kioupi & Voulvoulis, 2019). Without on-the-ground assessments, ICT integration efforts risk remaining ineffective.

The department's failure to track the progress of ICT implementation means there is no system to measure the effectiveness of workshops or identify barriers to their application. Without visiting schools to assess needs and progress, the department misses opportunities to provide targeted support and address challenges like infrastructure gaps or resource shortages. The participants' comments creates the impression that when the department provides support, it is merely an item to check off the list with little effort to ensure its success in practice. The perception that support is merely a box-ticking exercise suggests that ESD integration through ICT is far from reaching the department's priority list. Instead of fostering long-term sustainable change, the approach prioritises short-term appearances over real educational transformation.

Participant 2 insisted that there must be an official sent to check on the progress. For Msafiri et al. (2023), infrastructure must be properly maintained, ICT tools must be aligned with curriculum goals and teachers must develop their skills (through opportunities provided by leadership) in order for ICT integration to work. The lack of oversight also means that ICT tools are not tailored to curriculum goals, reducing their

ability to effectively integrate sustainability principles into mathematics teaching. Without proper alignment, ICT remains an isolated element rather than an enabler of ESD. Therefore, the department sending officials to check on progress after Professional Development sessions will serve as an opportunity to learn about potential improvements that could be made in future Professional Development which will ultimately improve ESD integration through ICT. As it stands, it appears that the department is out of touch with reality. Participant 5 added:

*It was early in 2012 ... We had a programme run by Vodacom. They taught us on a weekly basis. ... After the course ... they provided us with a smartboard afterwards. They provided laptops and some data, but they were limited to a few months if not six. ... They were teaching us how to use GeoGebra. ... It is just that there were a few conductors, people who were assisting us there. We could not really get attention to understand the program better, but at least we were exposed to the program at a certain level.*

It appears that there are external institutions that realise the need for ICT integration in schools. Participant 5 mentioned the regular Professional Development sessions offered by Vodacom. The duration of the programme, every Saturday over a couple of months, suggests a sustained effort to build teacher capacity over time, which is more likely to have a lasting impact than one-off workshops. However, this too was not without challenges. The data provided was for a limited time and teachers needed internet connectivity to access GeoGebra. Unfortunately, the teachers stopped using the resources when they had to pay for internet access themselves. Reliance on privately funded ICT initiatives means that only teachers with personal financial means can continue using these online tools. This contradicts ESD's principle of equitable access to quality education (Zickafoose et al., 2024).

It appears that there was no follow-up by the department on these Professional Development sessions. While these sessions provided initial exposure to GeoGebra, without follow-up sessions or extended access to resources, teachers are unlikely to develop confidence in using these tools effectively. This contradicts ESD's goal of long-term capacity building in education. This also confirms Participant 2's comment that the department does not want to deal with issues on the ground.

Participant 5 mentioned that the Professional Development conductors were not able to provide adequate individual attention, limiting the depth of understanding and practical mastery of GeoGebra. Without individualised attention, many teachers may feel overwhelmed or unsure about using ICT tools in their lessons. This may result in poor retention rates of ICT-based teaching methods, which directly impacts the long-term sustainability of ESD integration.

The lack of follow-up after professional development sessions emerges as a critical barrier to effective ICT and ESD integration. Initial exposure to tools like GeoGebra provides teachers with a basic understanding, but without reinforcement and ongoing support, they often lack the confidence to apply these tools in their classrooms. This disconnect between training and application discourages teachers from experimenting with learner-centred, participatory pedagogies, leading many to revert to traditional, teacher-centred methods that limit student engagement and critical thinking. Sustained support, including mentoring, peer collaboration, and refresher workshops, is essential for transforming initial awareness into practical competence. Without such measures, teachers may perceive ICT integration as an added burden rather than a vehicle for engaging learners in meaningful sustainability-focused problem-solving, undermining the transformative goals of ESD.

Participant 5 further elaborated:

*I've just recently attended a grade 12 workshop, and it was on probability... And it was supposed to be two sessions – the first session was the content part and then the second session was supposed to be where they introduce a certain program. They didn't tell us. They just said we must bring a laptop. But unfortunately, we never got to that part because they took the whole day looking at the content in part of the workshop, unfortunately. They gave us a website. I'm forgetting what it was. I've never even had an opportunity to look at that program. I did download it, but I've never had time to actually use it ...*

The workshop was planned to include both content and the introduction of a new program, but the entire day was consumed by content delivery. While this may reflect poor time management it also reflects the participants' sentiments that the ATP is too broad (as Participant 6 put it), such that even subject advisors (who usually run teacher

development programmes) cannot accommodate aspects like ICT. The participants also mentioned time constraints an issue in this context. A key principle of ESD is interdisciplinary learning, where learners engage with real-world sustainability issues using technology (SADC, 2022). However, if teachers receive limited ICT training, they lack the skills to integrate sustainability-driven principles into their mathematics lessons using effective digital tools.

This comment also highlights the poor prioritisation of the ICT component (which could have added more value to the participants' teaching practices) and a content-centric approach that goes beyond the classroom (which makes the CAPS objectives a mere façade). If ICT is only considered after core content has been covered, it will most likely be pushed aside by teachers in favour of curriculum completion. Indeed, Participant 5 admitted to downloading the program but never using it.

The participants were asked about any follow-up sessions after the Vodacom intervention. Here, Participant 4 made the following comment:

*No, there was no follow-up. And maybe it's difficult to talk about the department because you never know who is going to tell them.*

The participant's hesitation to discuss the department – "*You never know who is going to tell them*" – suggests a lack of trust or fear of punishment for being critical. This reflects broader concerns about transparency and openness within the education system, where teachers may feel hesitant to voice their concerns or critiques. ESD emphasises inclusive decision-making (Zickafoose et al., 2024) where teachers should have the freedom to discuss challenges and propose improvements. However, if teachers feel silenced by fear, they cannot actively contribute to shaping ICT-based ESD integration strategies in mathematics teaching. Participant 4 made the following remark:

*... like Participant 5 was saying, the department sources out people to come and train. They did that with the Vodacom. But you can tell that the presenters weren't really, you know, well versed with the information that they had to deliver. So, it will be difficult for them to proceed with programme, and they just traded it away.*

Participant 4's comment underscores dissatisfaction with the quality of Professional Development provided by the department which makes it less likely for the teachers to implement anything. Many (75%) participants expressed that their expectations of professional development were largely unmet, leaving them disillusioned about its value. For instance, several teachers anticipated hands-on training with ICT tools but instead received theoretical presentations focused on curriculum content. This mismatch reduced their confidence in experimenting with new technologies in their classrooms. Participant 5's admission that they downloaded an introduced program but never used it illustrates how initial enthusiasm can dissipate without sufficient support or practical follow-up. These experiences shaped teachers' perceptions of ICT and ESD integration as daunting or peripheral rather than essential components of their practice. In contrast, Participant 3 noted feeling more prepared and motivated after attending a well-structured SADTU workshop that included practical demonstrations, though the lack of follow-up still constrained sustained application. These reflections highlight the critical role of responsive, context-sensitive professional development in either reinforcing or undermining teachers' willingness to embrace innovative pedagogies for sustainability.

This also shows that even the department may not be committed enough to provide sound Professional Development. The quality of trainers providing Professional Development is crucial to learning (Popova et al., 2022). Also, had there been follow-up, the department would have had the opportunity to obtain insights about its Professional Development initiatives, allowing them to provide better Professional Development sessions with seasoned instructors in future. Indeed, follow-ups after Professional Development are reported as the most effective characteristic of Professional Development programmes (Popova et al., 2022). However, this does not appear to be a case. Participant 3 added the following:

*They even develop new lesson plans now. But what the department does is, they think of these ideas, but they don't know how to implement them. And they just give you a copy of a lesson plan and they say go do it and they leave it to us ...*

Providing teachers with new lesson plans without training or contextual explanation places an unfair burden on them to interpret and adapt these plans for their classrooms. This also underscores the fact that there is no follow-up from the department's side on

the successful implementation and execution of these lesson plans. Without structured guidance, teachers may struggle to interpret how to use ICT tools like GeoGebra, simulations, or real-world sustainability data in their lessons. Additionally, some teachers may quickly grasp how to use technology for sustainability-based mathematics teaching while others struggle without support. The lack of direction on the lesson plans provided widens this gap and can lead to unequal implementation of ESD-focused ICT lessons across schools.

#### **4.5. CONCLUSION**

The purpose of this study was to explore the integration of ESD into mathematics education through ICT. The data generated was intended to answer the following questions:

1. What is the level of awareness among mathematics teachers regarding the integration of ESD into mathematics instruction through the utilisation of ICT?
2. How do teachers in the Pinetown district utilise ICT tools to facilitate the integration of ESD principles into mathematics teaching practices?
3. To what extent is support provided to teachers to facilitate the integration of ESD into mathematics teaching through ICT?

The findings suggest that teachers are generally not aware of the concept of ESD or SDGs. As a result, there are no intentional efforts to integrate ESD into their mathematics classes. However, their practices do reflect some ESD determinants when teaching content that learners can relate to. The lack of knowledge about ESD calls for systematic and continuous Professional Development for teachers to enhance their understanding and recognition of the significance of ESD integration into mathematics while appreciating the enabling effect of ICT.

Given that teachers are generally unaware of ESD, it means that there is no deliberate attempt to use ICT to facilitate ESD integration (that is non-existent). However, teachers do make use of ICT tools in their mathematics classes, though to a very limited extent. This is due to several challenges, some of which are school-specific while others are beyond the institution's control.

Locally, the schools typically do not have adequate ICT infrastructure, internet connectivity or leadership support. External factors include curriculum demands, ineffective workshops, lack of financial and professional support by the Department of Basic Education, and the systemic focus on exam results over innovative teaching.

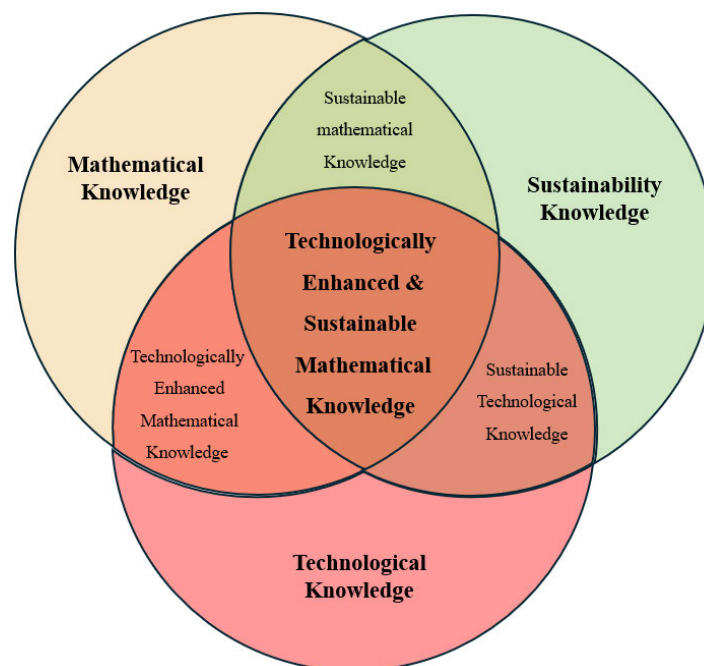
Despite these challenges, the teachers wish to continue to use ICT even though they are met with the financial burden of buying data and devices (like laptops) to get internet access. According to the findings of this study, schools generally have devices like projectors, which are shared among over 40 teachers and other (underutilised) devices donated by third-party organisations. Some schools have one ICT room that is shared by over 40 teachers. However, securing the ICT room is challenging, causing teachers not to utilise the available ICT. It can be concluded that normal teaching typically does not include ESD or ICT integration. Instead, it focuses on content and exams.

While some ESD determinants may be spotted in the CAPS document (aims of mathematics, for example, which is to develop “critical awareness of how mathematical relationships are used in social, environmental, cultural and economic relations” (DoE, 2011, p. 8)), the ATP appears not to be promoting ESD integration at all, let alone through ICT. As a result, the teachers in this study did not prioritise ESD or ICT. Furthermore, the teachers found the ATP too broad and with unrealistic timelines. Consequently, the teachers focused on completing the curriculum – right up to exam time. In the subsequent grades, the teachers found themselves reteaching content from previous grades. Consequently, lessons are rarely finished on time. Therefore, with all these challenges, ESD integration through ICT seems like a mythical ideal.

The data showed that Professional Development initiatives are offered by the department and third-party organisations. However, these have proven to be inadequate. The findings based on the Reflexive Thematic Analysis of the data suggested that the teachers in this study need targeted, effective and consistent Professional Development that will capacitate them to be better positioned to integrate ESD through ICT in their mathematics classes.

In this study, the integration of mathematical knowledge, sustainability knowledge, and technological knowledge emerged as critical aspects in understanding ESD integration in mathematics teaching through ICT. This is referred to as Technologically Enhanced

and Sustainable Mathematical Knowledge (TESMK). Figure 4.5 shows the intersection of the three knowledge domains.



*Figure 4.5: Emerging Conceptual Framework: Technologically Enhanced and Sustainable Mathematical Knowledge (TESMK) (Source: Author's own illustration)*

**Sustainable Mathematical Knowledge ( $MK \cap SK$ )** is knowledge that links mathematical concepts with sustainability principles in this study. Currently, teachers are teaching content with real-life examples. However, the teachers are not making an effort to teach learners to see value in the content. Instead, their teaching focuses on learners getting the marks required. All the lessons observed were centred around real-world examples with deliberate efforts to engage learners in critical discussions on sustainability issues.

**Sustainable Technological Knowledge ( $SK \cap TK$ )** is knowledge that leverages technology to promote sustainability, such as using digital tools. Teachers are using technology to a limited extent to improve the learning experience of mathematics for learners. This included projecting images onto a screen and stimulating discussions based on these. Teachers used technology to find information on the internet that fits intended topics while at the same time promoting sustainability practices. They walked into their classes with sustainability knowledge and technological knowledge.

**Technologically Enhanced Mathematical Knowledge ( $MK \cap TK$ )** is technological knowledge that enhances mathematics teaching. Teachers already possessed some technological knowledge and extensive pedagogical mathematical knowledge. Teachers are more comfortable with imparting knowledge using old methods of book, chalk and chalk board. This can also be attributed to challenges faced by teachers, like lack of infrastructure, which led to teachers walking into the classroom with less technological knowledge and more mathematical knowledge and leaning towards teaching methods that do not involve technology.

**Technologically Enhanced and Sustainable Mathematical Knowledge ( $MK \cap SK \cap TK$ )** represents the holistic integration of mathematical, sustainability, and technological knowledge. Lessons observed pointed to the intersection of mathematical, sustainability and mathematical knowledge where ICT was used to plan and deliver lessons with contents encouraging critical thinking on and discussions about sustainability issues.

This chapter outlined the results according to the themes identified from the data. The subsequent chapter offers a discussion of these findings in relation to the study's research questions. The findings presented in this chapter reinforce the significance of adopting a holistic approach to integrating ESD through ICT in mathematics education. Linking the results to Nerstrom's Transformative Learning Model illustrates how teachers' assumptions and beliefs about teaching can be challenged and transformed when exposed to sustainability-focused pedagogies. Similarly, Msafiri's ICT Integration Framework underscores the potential of ICT to act as an enabler for innovative teaching strategies that promote critical thinking and problem-solving. By situating the findings within these theoretical frameworks, the study highlights pathways for fostering transformative educational practices aligned with sustainable development goals.

# Chapter 5 | Discussion and Conclusion

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## 5.1 INTRODUCTION

The preceding chapter shared the data gathered from focus group discussions, classroom observations, and follow-up interviews. This chapter provides a synthesis of the findings, highlighting how the core research questions were addressed. This study aimed to investigate the integration of ESD into mathematics teaching through ICT. To achieve this, the study attempted to respond to the following research questions:

1. What is the level of awareness among mathematics teachers regarding the integration of ESD into mathematics instruction through the utilisation of ICT?
2. How do teachers in the Pinetown district utilise ICT tools to facilitate the integration of ESD principles into mathematics teaching practices?
3. To what extent is support provided to teachers to facilitate the integration of ESD into mathematics teaching through ICT?

Nerstrom's Transformative Learning Model was instrumental in understanding the integration of ESD while Msafiri's ICT Integration Framework was used to understand the use of ICT in mathematics teaching. The two frameworks were found compatible. Hence, both were employed in this study.

## 5.2 FINDINGS PERTAINING TO RESEARCH QUESTION 1

This section presents a summary of the findings related to Research Question 1 which sought to assess teachers' awareness levels of ESD.

### 5.2.1 Awareness and Understanding of ESD

The findings suggested that teachers are generally unaware of ESD and sustainability. Those teachers who do have some idea of sustainability only have a vague understanding of it. For them, this concept merely relates to environmental conservation. It is then no surprise that their teaching had no deliberate integration of ESD. This is consistent with the study by Waltner et al. (2020) which revealed that 79.7% of the participants confirmed that they had never heard of the concept of ESD, ESD programmes and sustainable development in general. Furthermore, while the UN's

17 Sustainable Development Goals are widely discussed around the world, the participants in this study were not able to name at least one of them. The findings of the current study suggest that while the teachers are generally not aware of ESD, their teaching does contain some ESD determinants. Likewise, Basson's study (2023) also established that in public secondary schools, there is some evidence of ESD integration in certain subjects even though the teachers were not fully aware of ESD.

### **5.2.2 Teachers' Implicit Integration of ESD**

Despite not knowing about ESD, teachers naturally incorporated sustainability-related concepts into their lessons. Although 75% (6 out of 8) of teachers were unaware of ESD, 62.5% (5 out of 8) demonstrated implicit integration of ESD-related practices in their mathematics lessons. For example, they used world graphs to discuss the impact of rhino poaching. These discussions promoted critical thinking and problem-solving on current issues in South Africa where rhino poaching is threatening the existence of the species (Nanima, 2019). In a similar way, Nthele and Muchanga (2021) emphasize that integrating environmental education into conservation strategies is essential for reducing poaching, as it fosters a behavioural appreciation for wildlife conservation among individuals.

The participants also used municipal bills, tariffs and consumption statistics to help convey sustainability related knowledge. In the financial mathematics section, the teachers discussed sustainable financial decisions as these relate to loans, investments and interest rates. While these (and other) sustainability concepts are embedded in the participants' teaching practices, the findings suggested that the participants were teaching the concepts simply because they are included in the ATP; the teachers focused on teaching for marks, exams and finishing the syllabus, not on sustainability. Similarly, Basson (2023) found that the tightly controlled ATP leaves very little room for innovative teaching that accommodates sustainability concepts. Furthermore, the figures provided by Waltner et al. (2020) highlight that if teachers are not even aware of ESD, they cannot be expected to deliberately integrate it into their lessons. Instead, they focused on traditional teaching goals like grades and syllabus coverage. While the participants attempted to infuse real-life examples into mathematics, the findings suggested that there were no real efforts to contextualise content in terms of the learners' immediate surroundings. In the financial mathematics section, for example, the teachers

could have used the local taxi industry, tuckshop businesses, street vending or brick laying – all which are common in peri-urban areas. Gula and Jojo (2024) also found that drawing on local indigenous knowledge systems can enrich mathematics teaching in rural South African primary schools to advance the sustainable development agenda. Such examples provide an opportunity for teachers to enable learners to apply what they are learning to improve the small businesses ran by their families. The inability to leverage ESD is a missed opportunity. The participants did not make a concerted effort to integrate ESD even after the researcher gave a brief explanation of some ESD core principles. Therefore, the participants could see the benefits of ESD integration even though their working conditions did not allow for this integration. Research supports this pattern across various contexts. Boeve-de Pauw et al. (2022) found that while teachers' self-efficacy for ESD increased after participating in professional development, it declined when they faced classroom realities and only improved again with sustained practice and support. Similarly, Hamwy et al. (2023) reported that teachers in Qatar recognised the importance of sustainability, yet more than half experienced moderate to significant challenges, particularly time constraints and rigid curricula, that hindered meaningful ESD integration. Siyam et al. (2025) also emphasised that professional development programs can enhance teachers' beliefs and self-efficacy toward using ICT in education, but without systemic support these gains often fail to translate into practice. Hunt et al. (2023) observed that while teachers' beliefs and practices are interdependent, professional development must intentionally address both to create lasting change. Collectively, these studies highlight that teachers' willingness alone is insufficient as structural and contextual factors play a critical role in enabling or constraining ESD integration.

### **5.2.3 Perceived Benefits of ESD Integration**

While there is no deliberate ESD integration, the teachers observed that real-world application of mathematics improved their learners' engagement. The teachers witnessed more participation by and interest from learners in lessons where mathematics was linked to everyday problems (e.g., budgeting, municipal tariffs, and sustainable construction). This made abstract concepts more accessible to learners. Likewise, Bulut and Borromeo Ferri (2025), in their study with tertiary-level students outside South Africa, found that using sustainability-themed modelling problems

strengthened students' problem-solving skills. Gula and Jojo (2024), whose study was based on the South African context, established that the ATP does not allow teachers the time to modify their teaching to accommodate contextualising every topic as this would require tackling the language barrier. Basson (2023), too, raised the issue of the language barrier. However, even with language as a barrier, ESD integration should not be treated as additional content but rather as something that can be deliberately woven into existing topics (such as financial mathematics and statistics) during lesson planning, without necessarily extending teaching time.

Additionally, the findings showed that while teachers appreciate the benefits of ESD integration, they are met with several barriers that force them to stick to what they call the "traditional way of teaching". This is characterised by teaching that is exam-centric and overly focused on syllabus completion. Likewise, Goller and Markert (2024), who analysed educators' perceptions, understanding, and beliefs about ESD in higher education, confirmed the finding that teachers do recognise the benefits of ESD integration but challenges such as finishing the syllabus seem to derail them.

#### **5.2.4 Barriers to Effective ESD Integration**

The findings of this study singled out time constraints as the main barrier to ESD integration and attributed this to the ATP which is described by the teachers as overladen, leaving them with limited time for additional content or innovative teaching. The findings allude to the notion that teachers are generally pressured to complete the syllabus. Hence, their main objective is content coverage and exams. These findings correspond with those from Naidoo's study (2019) which also established that the ATP dictates the pace at which content is to be taught which leaves very little room for meaningful integration of sustainability concepts into teaching. The ATP, according to the teachers, is so misaligned that it overlaps with teaching time. They always find themselves still trying to catch up with content, even during exams. As a result, they do not prioritise innovative teaching that promotes sustainability.

The data in Table 5.1 further substantiates the study's findings by offering concrete evidence of the time-related pressures teachers face in implementing the curriculum. Table 5.1 shows the official 2024 ATP and the official 2024 Exam schedule. As shown, in several instances (particularly in Grade 11 Term 1 and Grade 12 Term 1) the official

examination dates either coincide with or fall immediately after the final teaching days, leaving no meaningful time for revision or reflective engagement with content. For example, Grade 11 students write their Term 1 paper on the same day that revision begins, and Grade 12 students face a similar constraint with only a few days between their last topic and the first formal assessment (1 school day -the Friday 15<sup>th</sup> March and the weekend). This tightly packed schedule confirms teachers’ perceptions of the ATP as overloaded and rigid, echoing the findings of Naidoo (2019), who highlighted that the ATP dictates an unsustainable pace of instruction, prioritising content coverage over deep learning. The table also illustrates a lack of buffer periods, with teaching often continuing up to or beyond the start of exam periods, thereby reinforcing the notion that teachers are under constant pressure to cover the syllabus at the expense of pedagogical innovation. This crowding-out effect of exam-focused instruction leaves little opportunity for integrating ESD, which requires thoughtful engagement, interdisciplinary planning, and interactive methodologies. Hence, the scheduling misalignments presented in the table directly mirror the barriers identified in the study and provide tangible context for the systemic challenges educators face. Moreover, numerous studies (Malangen, 2021; Rajab and Motileng, 2024; Odiri, 2015; Yuan, 2022; Diehl and Bobak, 2021) have emphasized the spreading out of exam preparations over several days as this avoids students cramming for the exams, giving them more time to engage with the material.

*Table 5. 1 Alignment of Teaching, Revision, and Exam Dates for Grade 11 and 12 Mathematics adapted from official Grade 11 ATP 2024 (pp. 2-7), Grade 12 ATP 2024 (pp. 2-7) and Exam Schedule 2024 (pp. 2-8)*

<b>Class</b>	<b>Last Topic Date</b>	<b>Revision &amp; Testing</b>	<b>Official Exam Date</b>	<b>Content Assessed</b>	<b>Term</b>
<b>Grade 11</b>	22 Feb – 08 Mar (p.2)	11 Mar – 20 Mar (p.2)	11 Mar (1.5 Hours) – 1 Paper (p.2)	Term 1 work Only	Term 1
	29 May – 30 May (p.4)	31 May – 14 June (p.4)	Paper 1: 03 June (2 Hours) (p.3) Paper 2: 10 June (2 Hours) (p.3)	Term 2 work Only	Term 2
	28 Aug – 05 Sep (p.6)	06 Sep – 20 Sep (p.6)	16 Sep (1.5 Hours) – 1 Paper (p.4)	Term 3 work only	Term 3

	21 Oct – 25 Oct (p.7)	28 Oct – No Specific Date (p.7)	Paper 1: 15 Nov (3 Hours) (p.5) Paper 2: 18 Nov (3 Hours)	Term 1 to Term 4	Term 4
<b>Grade 12</b>	11 Mar – 14 Mar (p.2)	15 Mar – 20 Mar (p.3)	18 Mar (1.5 Hours) – 1 Paper (p.6)	Term 1 and Grade 11 work	Term 1
	23 May – 24 May (p.5)	27 May – 14 Jun (p.5)	Paper 1: 31 May (3 Hours) (p.7) Paper 2: 03 Jun (3 Hours) (p.7)	Not specified	Term 2
	08 Aug – 20 Aug (p.7)	21 Aug – 20 Sep (p.7)	Paper 1: 06 Sep (3 Hours) (p.8) Paper 2: 09 Sep (3 Hours) (p.8)	All Topics covered in both grade 11 and 12	Term 3

This study also found that, while the CAPS document somewhat promotes sustainability as indicated in the literature review, clear guidelines are not provided. Consequently, teachers feel that there are no proper guidelines on how sustainability could be infused into mathematics teaching. Similarly, Damoah and Adu (2022) asserted that while environmental education is part of CAPS, clear guidelines on how this integration could be achieved by teachers is lacking. Basson (2023) found disparities in ESD integration between public schools and private schools. ESD through ICT was deliberately promoted in public schools but not in public schools. This suggested non-existent nationally adopted guidelines for ESD integration. Naidoo (2019) also established that sustainability is somewhat promoted but not supported with clear guidelines.

The findings from this study show that language is also a barrier preventing learners from accessing content. All the participants in this study are from English medium schools with learners who are not English first language speakers. Therefore, the findings showed that learners struggle to unpack the real-life scenarios provided, particularly during exams. Language limits their ability to engage with complex, real-world problems. In response to this, the teachers are using a lot of isiZulu during their lessons. However, this was also troublesome for the learners since their mathematics

exams were not in isiZulu. In class, this approach can help learners to engage with content but it will not help them during assessments. This issue of language in South African schools is also underscored by Spaul (2016) who established that learners who are not first-language speakers of English found it hard to articulate themselves in English in numeracy assessments. This was discovered where grade 3 learners took the same test days apart in their home language and in English. Similarly, Taylor and Von Fintel (2016) observed that although using the mother tongue during the early years enhances learners' English proficiency in later grades, switching to assessments conducted solely in English can hinder performance in subjects such as mathematics. Furthermore, in a recent study done with grade 12 learners, the learners who took the test in their home language (Tshivenda) outperformed those who took the English version (Tshikondela et al., 2025), which further confirms the impact of language in the teaching of mathematics. Ultimately, this supports the finding that learners struggle to unpack real-world application scenarios in mathematics. Hence, ESD-centric content may suffer the same.

The current study revealed that, over and above teaching responsibilities, teachers must engage in administrative requirements like attending training workshops. These workshops typically focus on content with no intent to promote ESD interaction. Several studies reached the same conclusion, highlighting the inadequacy of the Professional Development of teachers to effectively integrate ESD into their teaching (Basson, 2023; Lotz-Sisitka, 2011; Olawumi & Mavuso, 2024; Parry & Metzger, 2023).

The current study revealed that the department treats the curriculum/syllabus as a one-size-fits-all endeavour. The study established that teachers are faced with large class sizes. For these teachers, tasks like grading student work takes time and offering properly differentiated instruction is a challenge. This finding is echoed by Milne and Mhlolo (2021), who argue that South Africa's Curriculum and Assessment Policy Statement (CAPS), while grounded in inclusive education principles, inadvertently enforces a rigid uniformity that undermines differentiated instruction. Furthermore, the study established that teachers are faced with large class sizes, which Milne and Mhlolo (2021) highlight as a significant contributor to teacher overload in overcrowded classrooms. Amid these challenges, the teachers did attempt to make use of ICT to improve the learning experience of mathematics.

## **5.3 FINDINGS PERTAINING TO RESEARCH QUESTION 2**

This section presents a summary of the findings related to Research Question 2 which sought to assess how teachers used ICT to facilitate the integration of ESD principles into mathematics teaching.

Given that teachers were not aware of the concept of ESD, it was established that there was no deliberate use of ICT to promote ESD. However, the participants did use ICT in their mathematics lessons to improve the learning experience of mathematics for their learners.

### **5.3.1 ICT Tools Teachers Use**

The findings suggested that the use of ICT in mathematics lessons is an occasional occurrence and that the teachers exhibit different levels of ICT competence. The teachers mostly used laptops and projectors while some had experience with apps like Desmos, GeoGebra, OneNote and GSP5. This finding corresponds with that of Mailizar and Fan (2020) who investigated Indonesian secondary school mathematics teachers' knowledge of ICT and its integration into their teaching practices. The finding also corresponds with that of Umugiraneza et al. (2018), who explored the use of technology in KwaZulu-Natal schools' mathematics classes.

Based on the findings, the teachers are seeing value in ICT integration such that they allow learners to bring their cell phones to school. The cell phones were used for apps like Desmos, research and past paper acquisition. Likewise, Fernandez and Fernandez (2021) and Ngesi et al. (2018) also explored the use of smartphones for educational purposes. Furthermore, third-party organisations like Siyavula and Vodacom sponsored some schools with computers and tablets, and in some cases, they provided internet data bundles for a limited time – a common practice in South African schools, especially in the peri-urban settings (Amedzo, 2007; Isaacs, 2007; Mangundu et al., 2025).

The findings of this study suggest that teachers do not prioritise learners using technology which appears to be common in schools in peri-urban areas. This finding corresponds with those from various other research studies (Graham et al., 2020; Graham et al., 2024; Netsianda & Ramaila, 2021; Umugiraneza et al., 2018; Zulu &

Mudaly, 2023). It was also established in this study that learners mostly used their cell phones visualisation and sometimes simulations. Incorporating interactive tools like Blooket and Kahoot where learners would also interact with technology was not prioritised. Likewise, various other studies also attributed this underutilisation to limited teacher knowledge or exposure, low confidence, focus on basic use like revision, and lack of meaningful integration of technology into teaching (Graham et al., 2020; Musasa et al., 2025; Netsianda & Ramaila, 2021; Umugiraneza et al., 2018).

While ICT holds great promise for facilitating learner-centred, interactive, and sustainability-driven pedagogy (Gula & Jojo, 2024; Naidoo & Reddy, 2023), the current study's findings reveal that mathematics teaching remains largely teacher-centred, with ICT mainly used for visualisation. This is consistent with Netsianda and Ramaila's findings (2021), where ICT was mostly limited to past papers and revision material. Such use does not align with the transformative, participatory ethos of ESD (SADC, 2022; UNESCO, 2022). Instead of fostering critical thinking and contextual problem-solving, ICT is reinforcing traditional didactic methods – an indication of either limited teacher competence or a lack of Professional Development aligned with ESD goals (Olawumi & Mavuso, 2024). The findings of this study confirmed that the limited use of available ICT tools can be attributed to the barriers that teachers encounter on a daily basis.

### **5.3.2 Barriers to Effective Use of ICT**

While teachers are keen to use ICT to improve their teaching and learning experiences, various challenges are preventing them from this ideal. The participants highlighted several challenges, with time constraint being the most prominent one. None of the participants' schools had ICT-equipped classrooms. As a result, the teachers needed to carry around projectors and laptops between classes and cope with time-consuming setup processes. Given the ATP demands, some teachers opted not to use ICT as often while others simply did not bother. Some teachers had to share one projector among at least 40 teachers, which made some of them stick to books and chalk boards. The challenges highlighted by the participants included the lack of ICT-equipped classrooms, the time-consuming process of setting up equipment, and the need to share limited resources like projectors among many teachers. These are not isolated incidents but reflective of broader, systemic issues within the South African education system.

As outlined in the literature, South African teachers often express a strong willingness to integrate ICT into their pedagogy (Musasa et al., 2025; Umugiraneza et al., 2018). However, the infrastructural realities hinder this ideal. Many schools lack designated ICT spaces or fixed equipment, forcing teachers to transport laptops and projectors between classrooms (an approach that is both time-intensive and impractical given the strict ATP requirements). This logistical burden discourages frequent ICT use, leading many teachers to revert to traditional chalk-and-talk methods. Moreover, as the literature points out, the limited availability of shared devices often results in booking conflicts or underutilisation (Musasa et al., 2025), echoing the participants' frustrations over competing for a single projector among over 40 staff members. These findings affirm that the barriers to ICT integration are not merely teacher-related but are deeply embedded in systemic infrastructure and policy limitations, particularly in peri-urban and under-resourced contexts.

The teachers found themselves carrying an unfair financial burden in their attempt to incorporate ICT in their teaching. None of the participants' schools had internet connectivity, which meant the teachers had to pay for their own data bundles. The teachers were using their own laptops running at a risk of damage/theft for which they will not be reimbursed should something happen. Furthermore, when learners bring their cell phones to school, they also do not have data bundles, which meant the teacher usually provides for this. The finding that teachers carry an unfair financial burden in integrating ICT is consistent with the systemic challenges identified in the literature. Zulu (2020) highlighted how schools in township areas are frequently targeted for theft, leading to the loss of essential ICT equipment. Similarly, Chisango and Marongwe (2021) reported that both school devices and learners' personal tools are often stolen, even en route to or from school. During the Covid-19 lockdown, more than 400 South African schools were vandalised, further emphasising the insecurity surrounding ICT resources (SABC News, 2020). Mangundu et al. (2025) observed recurring theft and vandalism in Pietermaritzburg schools. In such an environment, teachers risk losing personal equipment without reimbursement, and often end up covering connectivity costs for themselves and their learners. These conditions make sustainable ICT use extremely difficult and place a disproportionate burden on already stretched educators.

The findings of this study established that while the department promotes the use of ICT in schools, there seems to be lack of tangible efforts or support to provide schools with resources for teachers to integrate ICT in their teaching. This finding is strongly supported by literature.

While the current study highlights a lack of sustained and context-relevant Professional Development for integrating ESD through ICT, global experiences provide valuable insights for strengthening teacher support systems in South Africa. For example, studies from Finland, Croatia, and Malawi show that effective PD models often combine hands-on ICT training with sustainability-focused pedagogies. These approaches enable teachers to embed such practices meaningfully in their classrooms (Kang and Lund, 2024; Zovko et al., 2019; Gondwe, 2021). Programs that emphasize experiential learning, collaboration, and ongoing support have been particularly successful in shifting teacher mindsets and practices. These characteristics differ significantly from the fragmented and sporadic initiatives often observed in the South African context, where ICT training and sustainability education are seldom integrated. Adopting a similar approach, adapted to local resource constraints, could serve as a roadmap for designing PD initiatives that are impactful and scalable.

Graham et al. (2024) reported that over 50% of learners attend schools without ICT infrastructure while Munje and Jita (2020) noted the slow pace of integration due to systemic challenges. Netsianda and Ramaila (2021) highlighted barriers such as lack of ICT tools, training, and school-level support. Zulu (2020), Chisango and Marongwe (2021), and Mangundu et al. (2025) emphasised how theft and vandalism hinder ICT investment in township and rural schools. Additionally, poor internet connectivity, load-shedding, and device shortages persist despite departmental efforts (Musasa et al., 2025). These studies collectively confirm that the gap between ICT policy promotion and actual support remains a significant barrier in South African schools.

Additionally, the findings from this study highlighted attempts by third-party organisations to capacitate teachers on ICT integration while providing them with ICT tools. Likewise, Mangundu et al. (2025) investigated the barriers hindering sustainable ICT integration in public secondary schools in Pietermaritzburg. These initiatives show that there is recognition of the need to empower teachers, which is essential for meaningful ICT integration into ESD. Importantly, such support may boost teacher

confidence, spark interest in sustainability themes, and promote innovative, learner-centred pedagogy.

Although teachers exhibit a genuine enthusiasm for leveraging ICT to enrich their teaching and embed ESD principles in their teaching content, the systemic and structural barriers they face make this aspiration largely unattainable. The lack of ICT-equipped classrooms, combined with the time-consuming logistics of moving and setting up equipment amidst rigid ATP schedules, significantly hinders consistent ICT use. In addition, the burden of competing for a single shared projector among dozens of staff not only limits access but also reinforces reliance on traditional methods of instruction. Similar challenges have been observed in other developing contexts, where limited access to ICT infrastructure and shared equipment constrain teachers' ability to integrate technology effectively. For instance, in Azerbaijan, teachers reported having to borrow projectors in turn, which restricted opportunities for consistent ICT-enhanced lessons and resulted in a continued dependence on traditional teaching approaches (Babayeva, 2021). In Indonesia, English teachers highlighted insufficient equipment, poor internet connectivity, and time constraints as major obstacles to using ICT, forcing them to default to conventional methods (Juliana & Muslem, 2017). Likewise, in Liberia, the lack of ICT infrastructure, including projectors and institutional internet facilities, has been identified as a significant barrier to ICT integration in teacher education (Kennedy, 2023). In Ghana, basic school teachers faced similar issues, citing limited ICT tools and infrastructural inadequacies as factors that perpetuate reliance on traditional instructional practices (Nii Akai Nettey et al., 2024). These studies, though situated outside South Africa, are relevant as they highlight how systemic constraints in resource-constrained educational settings often limit teachers' agency in adopting ICT, underscoring the universality of these challenges in many developing countries.

Moreover, the financial strain placed on educators (who find themselves using their own laptops, fund internet access, and even subsidise learner connectivity) further establishes inequity and makes ICT integration unsustainable. The ever-present threat of theft and lack of compensation for damaged or stolen equipment worsen the situation, leaving teachers vulnerable and unsupported. Despite policy rhetoric promoting ICT integration, the absence of tangible, consistent support in the form of resources, security, training, and infrastructure has created a disconnection between policy intent

and classroom reality. Similar issues have been reported globally. For instance, Akram et al. (2022) revealed that in Pakistan, limited ICT infrastructure, slow internet, and insufficient teacher training undermine effective integration, despite supportive policies. In Bosnia and Herzegovina, Bećirović (2023) highlighted that teachers are often left to self-fund devices and software due to gaps between policy and implementation. In the South African context, Mathebula et al. (2025) found that weak institutional support, inadequate pedagogical training, and limited access to ICT resources perpetuate the disconnect between policy ambitions and classroom realities. Although some of these studies are situated outside South Africa, they provide valuable comparative insights from other developing countries facing similar systemic challenges, reinforcing the universality of these barriers to ICT integration.

This environment of scarcity and insecurity makes it nearly impossible for teachers to meaningfully integrate ESD through ICT. ESD, by nature, requires interactive, reflective, and participatory pedagogies (methods that ICT could enhance if appropriately supported). However, in the absence of basic infrastructure and institutional commitment, teachers are effectively restricted from realising the transformative potential of ESD through ICT. Othman et al. (2024) found that despite teachers in Malaysia being highly motivated to embed sustainability and the SDGs through ICT, systemic barriers such as inadequate infrastructure, poor institutional support, and lack of technical resources limited their ability to translate policy into practice. Similarly, Huang et al. (2024) highlighted that the absence of an overarching pedagogical framework and insufficient institutional commitment hindered Chinese teachers from leveraging digital technologies to enable learner-centred and sustainable education. In Nepal, Joshi and Khatiwada (2024) observed that outdated infrastructure, high technology costs, and minimal professional development prevented meaningful ICT integration, creating a disconnect between policy ambitions and classroom realities. From a Jordanian context, Almithqal and John (2024) reported that teachers faced barriers such as limited ICT access, inadequate training, and lack of technical support, which reinforced their reliance on traditional teaching approaches and blocked opportunities for transformative ICT use. Together, these findings across multiple developing contexts underscore how infrastructural inadequacies and institutional neglect restrict teachers globally from actualising the transformative potential of ESD through ICT.

## **5.4 FINDINGS PERTAINING TO RESEARCH QUESTION 3**

This section presents a summary of findings related to Research Question 3 which sought to assess the extent to which support was provided to teachers to facilitate the integration of ESD into mathematics teaching through ICT.

To critically situate the findings within the study's theoretical framing, it is important to consider how Nerstrom's Transformative Learning Model and Msafiri's ICT Integration Framework illuminate the challenges surrounding professional development. Nerstrom's model underscores that transformative shifts in teaching practice require both cognitive and structural support, which aligns with the finding that teachers' willingness to adopt ESD-ICT practices is constrained by systemic barriers. Msafiri's framework emphasizes the need for enabling environments that combine technological tools, teacher readiness, and institutional backing. The lack of deliberate professional development initiatives observed in this study reflects a gap in fostering such enabling environments. Together, these frameworks suggest that unless professional development explicitly integrates sustainability and ICT principles within a supportive system, efforts to promote ESD in mathematics will remain fragmented.

The findings from this study suggest that no deliberate Professional Development was aimed at capacitating teachers to use ICT for ESD integration, nor ESD integration alone. However, third-party organisations partnered with the department to provide ICT-related training for teachers; the departments involvement in the training merely had to grant the teachers permission to attend. Likewise, the literature review pointed to gaps in both pre-service and in-service teacher training in these areas (Basson, 2023; Imara & Altinay, 2021; Lotz-Sisitka, 2011; Olawumi & Mavuso, 2024). Additionally, the finding that some third-party organisations partnered with the department to provide ICT-related training is also supported by the literature (Mangundu et al., 2025), even though such initiatives were limited in scope and often lacked alignment with ESD objectives.

### **5.4.1 Teachers' Experiences with Professional Development**

According to the findings, the teachers in the study received Professional Development focused on ICT by third-party organisations like SADTU (a teacher's union) and

Vodacom. Based on the findings, the department has not made any real efforts to capacitate teachers to use ICT in their mathematics classrooms in Pinetown district. In 2018, Ojo and Adu also explored the effectiveness of ICT tools in teaching and learning in high schools in the Eastern Cape. They reported that the Western Cape, Northern Cape, and Gauteng had made progress in ICT implementation while other provinces (including KwaZulu-Natal where Pinetown District is situated) were still below the expected standards (Ojo & Adu, 2018). Since ICT-focused Professional Development is mostly provided by third-party organisations (e.g., SADTU, Vodacom), teachers in areas with limited NGO or corporate support may lack the training necessary to integrate ICT meaningfully into their teaching, let alone integrate ESD concepts.

The findings further suggested lack of commitment on the side of department as it relates to ICT-focused Professional Development. When teachers received Professional Development, there is never any follow-up or continuous Professional Development. As a result, they would stop trying to implement what they have been trained on. In some cases, the department would present sessions to introduce teachers to some ICT tools. However, these sessions mostly focused on content to be covered and not on the intended ICT aspects. The teachers received links to follow as self-study, ignoring the financial burden this would put on teachers in terms of internet connectivity. These findings are consistent with literature showing that the department's commitment to ICT-focused Professional Development is limited. Teachers often receive initial exposure to ICT tools but no structured continuous Professional Development (Mangundu et al., 2025). Also, many are left to navigate new technologies alone, with little training (Netsianda & Ramaila, 2021) or institutional support (Musasa et al., 2025). This leads to frustration and discontinuation of ICT implementation efforts in the classroom.

The study showed that, given the lack of ICT-equipped classrooms at the participants' schools, Professional Development sessions for teachers cannot be hosted at their schools, which negatively impacts ICT integration efforts. This finding is supported by literature indicating that over 90% of classrooms in South Africa are not equipped for ICT integration (Graham et al., 2024), making it difficult for teachers to implement ICT-related Professional Development. As a result, integration efforts remain low, particularly in under-resourced schools (Munje & Jita, 2020; Mangundu et al., 2025).

This finding points to a systemic failure on the part of the Department of Basic Education to create enabling conditions for ICT integration in schools which can be leveraged to facilitate ESD integration. The situation reflects a broader issue of policy-practice disconnect, where teacher support is not matched by adequate resource provision, particularly in under-resourced schools. Consequently, the department's role in facilitating equitable and effective ICT integration appears insufficient and inconsistent, which ultimately creates an environment that is not conducive to ESD integration through ICT.

Research underscores that even in countries where curriculum frameworks promote innovative teaching, implementation often falls short without supportive structures and professional development. For instance, El-Hamamsy et al. (2023) highlight how an adapted cascade PD model enabled teachers to scale digital education initiatives effectively in contexts requiring sustainability integration. Similarly, Munkhtuya (2022) demonstrates that redesigning ICT assignments to embed sustainability principles not only enriched pedagogy but also fostered greater teacher awareness and readiness for innovation. These global insights suggest that bridging the gap between policy aspirations and classroom practice requires systemic investment in teacher capacity-building, coupled with access to context-sensitive ICT resources.

The findings pointed out that the CAPS speaks of innovative teaching. Yet, this is not translated into the ATP. This finding is supported by literature showing that while CAPS promotes innovative and sustainability-focused teaching (DoE, 2011), the ATP remains rigid and prescriptive, limiting teachers' ability to implement these approaches in practice (Basson, 2023). This leaves teachers with no clear policy framework guiding how ICT should be used in mathematics teaching.

Emerging evidence from international contexts suggests that sustained, collaborative, and context-sensitive professional development can bridge gaps between policy frameworks and classroom realities. Studies highlight that teacher support systems built around experiential learning, ICT-enabled collaboration, and iterative reflection empower educators to move beyond syllabus-driven teaching (Kang & Lund, 2024; Gondwe, 2021). Embedding similar approaches into South Africa's professional development frameworks could address the challenges posed by rigid curricula and resource limitations. These interventions not only equip teachers with practical

strategies for integrating ESD and ICT but also cultivate agency and innovation within constrained environments (Soini et al., 2022; Ernst et al., 2020).

Consequently, teachers feel unsupported in navigating ICT integration, leading to poor adoption rates. This finding is supported by literature noting that while CAPS implies ICT use (DoE, 2011), it lacks clear guidelines for its integration into mathematics teaching. As a result, teachers feel unsupported in navigating ICT use, which contributes to low adoption and a continued reliance on traditional teaching methods (Musasa et al., 2025; Netsianda & Ramaila, 2021). It is worth noting that White Paper 7 (WP7) on e-Learning aimed to have ICT capable learners by 2013 which has not been achieved (Tshimanika, 2023). This shortfall reflects broader systemic challenges in policy implementation and suggests that learners are entering classrooms without the necessary digital skills to engage with sustainability-focused, technology-enhanced learning. As a result, efforts to integrate ESD through ICT remain limited, particularly in under-resourced contexts where support is most needed.

This study's findings align with global research highlighting that policy ambitions alone are insufficient to drive meaningful ICT and ESD integration. Soini et al. (2022) observed that without sustained institutional commitment and access to ICT-supported sustainability projects, teachers struggle to move beyond traditional pedagogies. Kang and Lund (2024) further emphasize that embedding computational thinking into ESD requires deliberate planning and hands-on support for educators. Such evidence underscores the importance of bridging systemic gaps to empower teachers with the skills and tools needed for transformative mathematics education.

The findings of this study clearly reveal a systemic shortfall in both policy implementation and practical support for teachers seeking to integrate ESD through ICT in mathematics education. While third-party initiatives have offered some relief, the Department of Basic Education's inconsistent involvement, lack of follow-up, inadequate infrastructure, and unrealistic expectations have left teachers unsupported and overwhelmed. The disconnect between curriculum intentions and classroom realities (intensified by rigid ATP and under-resourced schools) continues to undermine efforts toward transformative, sustainability-focused teaching. Without deliberate, sustained, and contextually responsive Professional Development, the integration of

ESD through ICT will remain an unfulfilled mandate rather than a lived classroom practice.

Finally, the analysis of the qualitative data generated in this study has resulted in the design of an emerging conceptual framework titled Technologically Enhanced and Sustainable Mathematical Knowledge (TESMK). This model represents the intersection of mathematical, sustainability, and technological knowledge observed in the participants' evolving teaching practices. While literature on ESD and ICT integration in mathematics exists, there is a scarcity of models that explicitly combine these domains in the South African peri-urban schooling context. TESMK can help to address this gap by illustrating how these knowledge domains can simultaneously be integrated to support sustainable and contextually relevant mathematics teaching. When this emerging framework is compared to existing models, it becomes evident that while several frameworks intersect with one or two of the domains, none fully encapsulates the triadic integration that TESMK offers.

For instance, Kelley and Knowles' Pulley Model (2016) emphasises interdisciplinary STEM learning but lacks direct engagement with sustainability principles. Gundu et al. (2025) addressed ICT-mediated collaboration in mathematics and science education but omitted the sustainability dimension. The Source–Knowledge–Use and Humanities–Science–Technology Model (SKU-HSTM) model by Yang et al. (2025) comes closest to TESMK in structure and intent, advocating for a knowledge cycle that combines humanities, science, and technology with fuzzy mathematics at its core. However, it does not explicitly target classroom pedagogy or teacher practices within ESD contexts. Technological, Pedagogical and Content Knowledge (TPACK)-based models provide insight into technological integration in content teaching but fall short of including sustainability as a core knowledge domain (Meletiou-Mavrotheris & Papanastasiou, 2024; Rodríguez Moreno et al., 2019).

Other frameworks such as the Service Learning ESD model (Martín-Sánchez et al., 2022) promote sustainability and real-world engagement but are limited in their attention to mathematical or technological depth. Similarly, the algorithmic Collaborative Structure Search Framework (CSSF) (Liu et al., 2024) and the Technological Sustainability Assessment (TSA) model (Vacchi et al., 2021) provide

robust models for personalised learning and technological assessment, yet these lack pedagogical or subject-specific depth relevant to mathematics education.

Therefore, TESMK fills a crucial gap by proposing a holistic model that brings together all three domains (mathematical, technological, and sustainability knowledge) through a pedagogical lens, aimed at transforming both teacher practices and learner experiences in mathematics education aligned with ESD goals.

To consolidate the findings and highlight how each research question was addressed, Table 5.2 summarizes the key insights derived from the data, their interpretation within the context of the study, and corresponding recommendations.

*Table 5. 1 Summary of Research Questions, Key Findings, Discussion, and Recommendations*

<b>Research Question</b>	<b>What is data saying</b>	<b>Discussion</b>	<b>Recommendations</b>
<b>1. What is the level of awareness among mathematics teachers regarding ESD and ICT integration?</b>	Most teachers are unaware of ESD and its principles; those who are aware have a vague understanding. Some unintentionally include sustainability-related content.	Lack of awareness is the key barrier. Teachers focus on syllabus completion due to ATP pressure. Missed opportunities to localize content for learners.	Provide structured Professional Development on ESD. Include ESD explicitly in CAPS and ATP with local context examples. Raise awareness of SDGs and how to integrate them in math.
<b>2. How do teachers use ICT to facilitate ESD integration in mathematics?</b>	ICT is occasionally used, mostly for visualization and revision. No deliberate use for ESD. Limited use of tools like GeoGebra and Desmos.	ICT use is limited by lack of infrastructure, time, and security issues. Teachers carry financial burden and face scheduling barriers.	Equip schools with secure ICT infrastructure. Support teachers with training, resources, and clear guidelines on using ICT for ESD. Reduce ATP load to allow time for innovation.
<b>3. What support is provided to teachers to integrate ESD through ICT?</b>	No formal training by DBE. Some training from third parties (e.g., SADTU, Vodacom), but	There is a gap between policy and practice. ATP contradicts CAPS' call for innovation. Teachers	Provide continuous, hands-on PD aligned with school realities. Update ATP to reflect innovative approaches.

	not aligned with ESD. PD sessions lack follow-up.	are left unsupported and overwhelmed.	Create a national framework for ESD-ICT integration.
<b>Emerging Insight: TESMK Framework</b>	Data revealed overlapping domains of math, technology, and sustainability.	Current models miss this 3-way integration. TESMK addresses this gap.	Develop and Adopt TESMK like frameworks in teacher training and policy. Use it to guide classroom practice and curriculum planning.

As illustrated in Table 5.2, the study revealed systemic challenges and missed opportunities in integrating ESD through ICT in mathematics teaching. While some promising practices were identified, these remain incidental rather than deliberate due to structural constraints, limited awareness, and inadequate support. This final chapter offers detailed recommendations to bridge this gap and support transformative teaching practices in line with ESD goals.

To strengthen these recommendations, it is valuable to consider successful Professional Development models from international contexts that integrate ESD and Information and Communication Technology (ICT). Programs such as the Rivers2Lake education initiative (Ernst et al., 2020), sustainability-themed coding workshops in Finland (Kang & Lund, 2024), and ICT-supported sustainability projects in Croatia (Zovko et al., 2019) provide compelling examples of how active, participatory learning and collaborative approaches can empower teachers to adopt innovative practices. These models emphasize sustained support, hands-on training, and the thoughtful use of digital tools to enhance ESD integration. Embedding similar strategies into South African mathematics teacher training could help address systemic constraints such as curriculum rigidity, limited infrastructure, and insufficient institutional support. Moreover, adapting these approaches to local realities may foster teacher confidence and agency, enabling them to navigate challenges and transform mathematics classrooms into spaces for sustainability-focused, ICT-enhanced learning.

## **5.5 LIMITATIONS**

A noted limitation of this study is that certain participants were not involved in every phase of the data generation process. A much larger sample could have been used to account for any participants pulling out of the study.

Another limitation of the study is that it involved only schools in peri-urban areas. Hence, findings from this study may not be transferred to all types of schools. Moreover, the participants of this study came from three schools in the Pinetown district. Therefore, the findings from the research cannot be transferred to all districts or schools. A much larger sample involving more schools from multiple districts would present a stronger case.

Another limitation is that the engagement with the participants was not long enough to notice any change in their beliefs and perspectives after having their perspectives challenged, as suggested by Nerstrom's Transformative Learning Model (Nerstrom, 2014). Observing multiple lessons over time would have provided some insight into what the teachers have adopted (if at all).

## **5.6 RECOMMENDATIONS**

Drawing from the study's findings, this section outlines recommendations targeted at various stakeholders within the education sector.

### **5.6.1 For Policymakers**

The department must integrate clear ESD and ICT directives from the CAPS document down to the ATP. This should include specific ICT tools for different topics to encourage structured usage. Furthermore, the ATP will need to be streamlined through proper planning to allow teachers ample time to plan and execute innovative teaching while having enough time for revision and formal assessments.

Teachers should then be provided with continuous Professional Development for the specific ICT tools that facilitate the integration of ESD. This should come with follow-ups to assess how well ESD integration is facilitated through ICT, to support teachers, and to improve future Professional Development. With ESD being a new concept for

some teachers, a clear framework for embedding ESD concepts into mathematics could benefit teachers. The Professional Development sessions should include examples that demonstrate ESD integration across different mathematics topics.

### **5.6.2 For Schools**

Schools need to invest in proper security. This requires engagement with other stakeholders in government and third parties to provide the financial support required to secure the schools. Furthermore, school management needs to take an active role in sourcing funding and focus on the maintenance of infrastructure. The maintenance will also require a dedicated team within the school.

School leaders must prioritise having ICT-equipped classes which include physical equipment and internet services creating an environment conducive to ESD integration through ICT. The equipment procured should allow use by learners which will allow teachers to employ several interactive online ICT resources.

### **5.6.3 For Teacher Training Programmes**

The department must provide Professional Development that is practical and hands-on. This may include school-based workshops where teachers apply ESD integration through ICT in real lessons as opposed to taking teachers to centres with all the required resources while schools do not have these resources. To cater for under-resourced schools, Professional Development sessions should focus on free or affordable ICT tools. Furthermore, the department could invest in ICT and ESD mentors who are well versed in this area to provide continuous support.

### **5.6.4 For Future Research**

Future research may investigate the integration of ESD through ICT on a larger scale. The study would be long-term and involve a much larger sample where the population is made up of multiple schools from different districts and representing all provinces. This kind of research would potentially provide a holistic understanding of state of ESD integration, challenges and opportunities.

Future research may also extend this work by developing a context-specific model that highlights an integration of mathematical knowledge, technological knowledge and sustainability knowledge.

Future studies may investigate the role of AI in supporting ESD and ICT integration. Here, the focus will be on exploring how IA-powered tools (like ChatGPT and MS Copilot) can assist teachers in designing ESD-aligned lessons. Such a study could also include exploring the potential of adaptive learning technologies to personalise ESD-integrated instruction.

Future studies could also focus on addressing language barriers in ESD-integrated mathematics instructions. Such work could examine how students' limited English proficiency impacts their understanding of ESD-integrated mathematics concepts. This will include assessing whether students struggle more with word problems related to sustainability than with standard mathematics exercises.

Future work could explore the role of teacher beliefs and attitudes in ESD and ICT adoption. Such work could investigate how teachers' mindsets influence their willingness to integrate ESD and ICT in mathematics lessons.

## **5.7 CONCLUSION**

This study sought to explore the integration of ESD into mathematics teaching through ICT. This chapter concluded this exploration by presenting a discussion of the data analysis and findings. To strengthen the alignment between the research objectives and the study outcomes, it is worth revisiting the research questions posed in Chapter 1.

- What is the level of awareness among mathematics teachers regarding the integration of ESD into mathematics instruction through the utilisation of ICT? This study found that most teachers are unaware of ESD and the SDGs, with only incidental inclusion of sustainability-related content in their lessons.
- How do teachers in the Pinetown district utilise ICT tools to facilitate the integration of ESD principles into mathematics teaching practices? While teachers use ICT occasionally, such usage is often limited to visualisation and revision rather

than facilitating ESD integration, mainly due to infrastructural and systemic challenges.

- To what extent is support provided to teachers to facilitate the integration of ESD into mathematics teaching through ICT? The findings revealed that professional development opportunities are sporadic, lack follow-up, and are not aligned with ESD objectives, leaving teachers without adequate support.

By addressing these research questions, the study highlights critical gaps in policy, practice, and teacher support systems that must be addressed for effective ESD-ICT integration in South African mathematics education.

The findings further identified key challenges that hinder teachers' ability to integrate ESD meaningfully through ICT:

- Insufficient ICT infrastructure in schools (e.g., lack of computers, no internet connectivity, and unreliable electricity)
- The time-consuming task of carrying around and setting up ICT equipment in different classrooms
- Curriculum overload and time constraints
- Insufficient support from the Department of Education
- Security concerns (theft of ICT resources in schools)
- Lack of explicit policy guidance in the Annual Teaching Plan (ATP)
- Teacher training that was sporadic, lacked follow-up, and was not aligned with classroom realities
- The inability of the Department of Education to systematically track ICT implementation.

Although these challenges are significant, insights from other countries offer potential pathways forward. Successful professional development models in Malawi, Mongolia, Switzerland, the United States, and across Europe demonstrate the value of continuous, collaborative teacher learning, integration of ESD with ICT practices, and sustained mentoring to support innovation in classrooms. For example, programs such as the adapted cascade model for digital education in Switzerland, the Rivers2Lake program

in the United States, and ICT-based ESD assignments in Mongolia illustrate how participatory and context-responsive approaches can foster transformative change. Global reviews of technology-mediated professional development in low- and middle-income countries also emphasize the importance of locally adapted, blended learning modalities and peer support. Adapting such strategies to South Africa's unique educational context could help bridge the gap between policy aspirations and classroom realities.

Ultimately, this study underscores that teachers' willingness alone cannot drive change. Without deliberate and sustained systemic support, ESD integration through ICT will remain aspirational. A coordinated top-down approach, starting from curriculum planning and extending to school-level infrastructure and teacher development, is essential for transforming mathematics education into a vehicle for sustainability.

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# APPENDIXES

## Appendix A: Principal consent letter and declaration



### Informed Consent Letter to School Principal

Dear Principal

Ms/Mrs/Mr/Dr.....

Name of school .....

### Re: Permission to conduct a research project in your school

I am writing to request your permission to conduct a research project in your school. This project is titled:

**Exploring the integration of ESD in mathematics teaching through ICT: A Multiple case study.**

My name is Mziwendoda Dzanibe, and I am a researcher specializing in mathematics education at the University of KwaZulu-Natal (UKZN). I am reaching out to seek your valued collaboration for an important research project aimed at enhancing the skills of mathematics teachers, aligning them with the demands of the 21st century, specifically focusing on technology integration and Education for Sustainable Development (ESD).

To facilitate this research, I am seeking the participation of four mathematics teachers from your esteemed institution. This diverse group would include two teachers from the Senior

Phase (SP) and two from the Further Education and Training (FET) phase. Your consent for their involvement in this project would be invaluable.

If agreeable, the selected teachers will be invited to partake in a series of activities, including responding to a concise questionnaire, engaging in enlightening focus group discussions, participating in a teacher Professional Development workshop, and allowing observation during their teaching sessions to assess the integration of ESD principles through ICT. It is crucial to note that the incorporation of ESD is gaining prominence, as evident in the ongoing revamping of the CAPS curriculum to include ESD across all school subjects in the South African context.

All focus group discussions with the participants will be recorded using a Dictaphone and subsequently transcribed verbatim to ensure accuracy. The acquired data is pivotal for the analysis and completion of the research, which will be disseminated with the participant's permission.

To minimize disruptions, all data generation activities will take place on your school premises after regular teaching hours, with due consideration given to lunch breaks and free periods. I assure you that participants will be encouraged to take breaks and have lunch during discussions, and every effort will be made to ensure minimal interference with their regular schedules.

Your school's participation will significantly contribute to advancing mathematics education. I appreciate your consideration and await your positive response.

**Please note:**

\* Times and dates of this data generation process will be at your sole discretion. I have merely presented you with an outline of what I intend to do, however, you are free to make any changes and suggestions, if necessary.

\* Participation is completely voluntary, and participants have the right to withdraw from this study at any time. They will not be penalized if they choose to do so.

\* Confidentiality and anonymity will be maintained at all times. The identity of your school and all participants will not be revealed at any time, as pseudonyms (different names) will be used to protect everyone's right to privacy.

\* Any information provided by the participants will not be used against them, or the school, and will be used for purposes of this research only.

\* Participation in this study will not result in any cost to your school or the participants.

\* Neither the participants nor your school will receive financial remuneration. However, costs incurred by participants as a result of their involvement in this project will be covered.

\* This study does not intend to harm the participants in any way.

\* All participants will be handed letters of consent which they will have to carefully read and sign before I begin data generation.

I may be contacted at:

Email: 210501841@stu.ukzn.ac.za/dzanibem@gmail.com

Cell: 082 882 9526

You may also contact the Research Office through:

HSSREC Research Office,

E-mail: HSSREC@ukzn.ac.za

I If you would like any further information or if you are unclear about anything, please feel free to contact me at any time. Your co-operation and consent will be greatly appreciated.

If you grant permission to conduct this research at your school, please complete the form below and return it to me.

Warm regards,

Mr. Mziwendoda Dzanibe (Researcher).

**DECLARATION**

I ..... (full name/s of school principal) of ..... (name of school) hereby confirm that I understand the contents of this document and the nature of this research project, and I consent to the teachers participating in this research project. I also grant permission for my school to be used as the research site.

*Additional consent*

I understand that focus group discussions will be audio-recorded and I grant permission for this.

YES/NO

I understand that the teachers and the school are free to withdraw from the research project at any time.

YES/NO

**SIGNATURE OF SCHOOL PRINCIPAL**

**DATE**

.....

.....

## Appendix B: Educator consent letter and declaration



### Informed Consent Letter to the Teacher

Dear Teacher

Ms/Mrs/Mr/Dr.....

Name of school .....

#### **Re: Permission to conduct a research project with you**

I am writing to request your permission to conduct a research project in your school. This project is titled:

**Exploring the integration of ESD in mathematics teaching through ICT: A Multiple case study of the KwaZulu-Natal Province.**

My name is Mziwendoda Dzanibe, and I am a researcher in mathematics education at the University of KwaZulu-Natal (UKZN).

I am reaching out to extend a special invitation for your participation in a significant research project focusing on enhancing the skills of mathematics teachers, particularly in the integration of Education for Sustainable Development (ESD) through Information and Information and Communication Technology (ICT). Your valuable insights and experiences are crucial to the success of this initiative.

If you choose to participate, you will be involved in activities such as responding to a brief questionnaire, engaging in enlightening focus group discussions, participating in a teacher Professional Development workshop, and allowing observation during your teaching sessions to assess the integration of ESD principles. It is noteworthy that the incorporation of ESD is gaining prominence, as seen in the ongoing revamping of the CAPS curriculum.

All discussions will be recorded for accuracy and analysis purposes. Your contribution will be vital for the completion of the research and the subsequent write-up of journal articles.

To minimize disruptions, all activities will take place on school premises after regular teaching hours, with due consideration given to breaks and free periods. Rest assured, participants will be encouraged to take breaks and have lunch during discussions, and every effort will be made to ensure minimal interference with your regular schedule.

Your participation in this research project will not only contribute to the advancement of mathematics education but also provide a valuable opportunity for Professional Development in line with the evolving educational landscape.

**Please note:**

\* Times and dates of this data generation process will be at your sole discretion. I have merely presented you with an outline of what I intend to do, however, you are free to make any changes and suggestions, if necessary.

\* Participation is completely voluntary and participants have the right to withdraw from this project at any time. They will not be penalized if they choose to do so.

\* Confidentiality and anonymity will be maintained at all times. The identity of your school and all participants will not be revealed at any time, as pseudonyms (different names) will be used to protect everyone's right to privacy.

\* Any information provided by the participants will not be used against them, or the school, and will be used for purposes of this research only.

\* Participation in this project will not result in any cost to your school or the participants.

\*Neither the participants nor your school will receive financial remuneration. However, costs incurred by participants as a result of their involvement in this project will be covered.

\* This project does not intend to harm the participants in any way.

I may be contacted at:

Email: 210501841@stu.ukzn.ac.za/ [REDACTED]

Cell: [REDACTED]

You may also contact the Research Office through:

HSSREC Research Office,

E-mail: [HSSREC@ukzn.ac.za](mailto:HSSREC@ukzn.ac.za)

If you would like any further information or if you are unclear about anything, please feel free to contact me at any time. Your co-operation and consent will be greatly appreciated.

If you grant permission to conduct this research at your school, please complete the form below and return it to me.

Warm regards,

Mr. Mziwendoda Dzanibe (Researcher).

**DECLARATION**

I ..... (full name/s of an teacher) of  
..... (name of school) hereby confirm that I understand  
the contents of this document and the nature of this research project, and I agree to participate  
in this research project.

***Additional consent***

I understand that focus group discussions will be audio-recorded and I grant permission for  
this.

YES/NO

I understand that I am free to withdraw from the research project at any time.

YES/NO

**SIGNATURE OF AN TEACHER**

**DATE**

.....

.....

## Appendix C: The participants' qualifications

Pseudonym	School	Location type	Phase teaching	Qualification
P1	A	Rural	GET	BEd Hon
P2	A	Rural	GET+FET	BEd
P3	A	Rural	GET+FET	BEd
P4	B	Township	GET+FET	BEd Hon
P5	B	Township	GET+FET	BEd
P6	B	Township	GET+FET	BEd
P7	C	Rural	GET+FET	BEd
P8	C	Rural	GET+FET	PGCE

## Appendix D: Focus Group Discussion schedule



Umlazi P

4066

### Focus Group Interview Schedule

I am Mziwendoda (Nicholas) Dzanibe a Master of Education student from the University of KwaZulu-Natal. During this session, I will be asking you questions related to the use of ICT to promote ESDs in your mathematics classes. I will be recording audio of our session which will be later transcribed and analysed for the sole purpose of this study. Please note that there are no right or wrong answers and I would encourage you to speak freely. Information shared during this session remains completely confidential and will only be shared with researchers in this project and the University of KwaZulu-Natal. Data collected here will be stored safely for 5 years after which it will be permanently destroyed. Your identity will not be revealed at any point. Aliases will be used to refer to all participants of this endeavor.

School pseudo name	School A	School A	School A	School A
Teacher pseudo name	Teacher 1	Teacher 2	Teacher 3	Teacher 4
Phase Teaching				
Number of Students				

**What is the level of awareness among mathematics teachers regarding the integration of Education for Sustainable Development (ESD) into mathematics instruction through the utilization of ICT?**

- |    |  |
|----|--|
| 1. | Imagine you're preparing a lesson on any topic of your choosing. How would you incorporate principles of sustainable development within this lesson using ICT tools? |
|----|--|

2.	Reflecting on your teaching practice, have you consciously integrated themes of sustainability or environmental awareness into your mathematics lessons before? If so, could you provide an example of how you did this?
3.	Consider the current curriculum guidelines for mathematics in KwaZulu-Natal. Do you feel there's adequate emphasis on integrating ESD principles? Why or why not?
4.	Think about the Professional Development opportunities you've had. Have any of them focused on incorporating ESD into mathematics teaching? How effective were they?
5.	Imagine you're discussing the role of technology in education with a colleague who is unfamiliar with ESD integration. How would you explain its importance and potential impact on mathematics teaching?

**How do teachers in the KwaZulu-Natal Province utilise ICT tools to facilitate the integration of ESD principles into mathematics teaching practices?**

1.	Let's imagine a typical mathematics class where ICT tools are available. Could you walk us through how you would use these tools to teach a concept while incorporating principles of sustainable development?
2.	Reflect on a recent lesson where you used ICT in your mathematics class. Were there any moments where you consciously included ESD principles? If yes, what were they?
3.	Considering the diverse range of ICT tools available, which ones do you find most effective for integrating ESD into mathematics teaching? Can you provide examples of how you've used them?
4.	How do you ensure that the use of ICT in your mathematics classes not only enhances learning outcomes but also promotes environmental awareness and sustainability?
5.	In your opinion, what additional support or resources would be helpful for mathematics teachers in KwaZulu-Natal to better integrate ESD principles through ICT?

**What are the benefits associated with the integration of ESD in mathematics teaching through ICT?**

1.	Thinking back on your experiences, can you share any positive outcomes or benefits you've observed when integrating ESD principles into mathematics lessons using ICT?
2.	How do you perceive the impact of integrating ESD in mathematics teaching on students' understanding of real-world issues and their motivation to learn?

3.	Have you noticed any changes in students' attitudes or behaviors towards sustainability after implementing lessons that integrate ESD principles through ICT? If so, could you describe these changes?
4.	From your perspective, how does the integration of ESD in mathematics teaching through ICT contribute to students' overall development as responsible citizens?
5.	Reflecting on your teaching practice, how has incorporating ESD principles through ICT enhanced your professional growth and satisfaction as a mathematics teacher?

**What are the challenges associated with the integration of ESD in mathematics teaching through ICT?**

1.	Can you identify any barriers or challenges you've encountered when attempting to integrate ESD principles into mathematics teaching through ICT?
2.	How do constraints such as limited access to technology or lack of technical skills among teachers impact the effective integration of ESD in mathematics instruction?
3.	Reflecting on societal attitudes or perceptions, have you faced any resistance or skepticism from students, colleagues, or parents toward the incorporation of sustainability themes in mathematics classes?
4.	Considering the curriculum requirements and time constraints, how do you prioritize between covering core mathematical concepts and integrating ESD principles through ICT?
5.	In your opinion, what systemic changes or support mechanisms are needed at the school or district level to overcome these challenges and promote effective integration of ESD in mathematics teaching through ICT?

## Appendix E: Observation schedule



Umlazi P

Durban

4066

### Observation Schedule

I am Mziwendoda (Nicholas) Dzanibe, a Master of Education student from the University of KwaZulu-Natal. During this session, I will be observing your lessons and taking notes. The aim is to look for the use of ICT to promote ESDs in your mathematics lessons. I am not judging your teaching, but I will be a silent observer with zero participation in the lesson. Please try to teach your lesson as normally as possible. Information collected during this session remains completely confidential and will only be shared with researchers in this project and the University of KwaZulu-Natal. Data collected here will be stored safely for 5 years after which it will be permanently destroyed. Your identity will not be revealed at any point. Aliases will be used to refer to all participants of this endeavour.

School pseudo name	School A
Teacher pseudo name	Teacher 1
Phase Teaching	
Number of Students	

**What is the level of awareness among mathematics teachers regarding the integration of Education for Sustainable Development (ESD) into mathematics instruction through the utilization of ICT?**

**NOTES**

1.	<b>Introduction of ESD Concepts:</b> Observe how teachers introduce ESD concepts and principles at the beginning of the lesson.	
2.	<b>Integration of ICT:</b> Assess how teachers incorporate ICT tools into their lessons to support the integration of ESD in mathematics instruction.	
3.	<b>Clarity of Instruction:</b> Note the clarity and coherence of the teacher's instructions regarding the integration of ESD and ICT.	
4.	<b>Demonstration of Awareness:</b> Look for evidence that teachers demonstrate awareness of ESD principles and their relevance to mathematics teaching.	
5.	<b>Engagement Strategies:</b> Observe the strategies used by teachers to engage students in discussions or activities related to ESD and ICT integration.	

<b>How do teachers in the KwaZulu-Natal Province utilize ICT tools to facilitate the integration of ESD principles into mathematics teaching practices?</b>		<b>NOTES</b>
1.	<b>Selection of ICT Tools:</b> Assess the appropriateness of the ICT tools selected by teachers for facilitating ESD integration in mathematics teaching.	
2.	<b>Alignment with ESD Principles:</b> Observe how teachers ensure that the ICT tools used align with ESD principles and objectives.	
3.	<b>Integration with Content:</b> Note how teachers seamlessly integrate the use of ICT tools with mathematics content while addressing ESD themes.	

4.	<b>Student Interaction:</b> Assess how teachers encourage student interaction and collaboration when utilizing ICT tools for ESD integration.	
5.	<b>Feedback and Reflection:</b> Look for evidence that teachers provide feedback and opportunities for student reflection on their use of ICT tools in relation to ESD integration.	

What are the benefits associated with the integration of ESD in mathematics teaching through ICT?		NOTES
1.	<b>Student Engagement:</b> Observe the level of student engagement and participation during activities that integrate ESD principles through ICT.	
2.	<b>Understanding of Concepts:</b> Assess whether students demonstrate a deeper understanding of mathematical concepts as a result of ESD integration using ICT.	
3.	<b>Real-World Connections:</b> Note instances where students make connections between mathematical concepts and real-world sustainability issues.	
4.	<b>Critical Thinking Skills:</b> Look for evidence of students' critical thinking skills being developed through activities that integrate ESD and ICT.	
5.	<b>Student Reflection:</b> Observe opportunities for students to reflect on the benefits of ESD integration in mathematics teaching through the use of ICT.	

What are the challenges associated with the integration of ESD in mathematics teaching through ICT?	<b>NOTES</b>
1. <b>Technological Issues:</b> Note any technical challenges or disruptions encountered during the lesson that hinder the integration of ESD through ICT.	
2. <b>Time Management:</b> Assess whether teachers effectively manage time constraints while incorporating ESD principles and ICT tools into the lesson.	
3. <b>Student Engagement:</b> Observe any instances where students demonstrate disengagement or lack of interest in activities related to ESD integration through ICT.	
4. <b>Differentiation:</b> Look for evidence that teachers differentiate instruction to meet the diverse needs of students while integrating ESD and ICT.	
5. <b>Addressing Misconceptions:</b> Assess how teachers address misconceptions or resistance from students regarding the relevance of ESD integration in mathematics teaching through ICT.	

## Appendix F: Post-Observation interview schedule



School of Education, College of Humanities,

University of KwaZulu-Natal,

Edgewood Campus, KwaZulu-Natal

I am Mziwendoda (Nicholas) Dzanibe, a Master of Education student from the University of KwaZulu-Natal. During this session, I will be asking questions related to the lesson observed. This will be a short 5-minute interview which comprise of 5 questions. Information collected during this session remains completely confidential and will only be shared with researchers in this project and the University of KwaZulu-Natal. Data collected here will be stored safely for 5 years after which it will be permanently destroyed. Your identity will not be revealed at any point. Aliases will be used to refer to all participants of this endeavour.

School pseudo name	School A
Teacher pseudo name	
Age	
Gender	
Race	
Language(s)	
Residential area	
Education level	
Number of Years teaching	
Phase Teaching	

Qualifications	
Number of Students	

### Post-Observation Interview Schedule

No.	Interview Questions
1.	Describe how you incorporated ICT tools to facilitate the integration of Education for Sustainable Development (ESD) principles in this lesson?
2.	Describe the impact of ICT on students' understanding of the connection between mathematical concepts and real-world sustainability issues?
3.	What parts or aspects of the lesson were intended to encourage student interaction and engagement during the lesson through ICT and ESD integration?
4.	What challenges did you face in, lesson planning, managing time and addressing diverse student needs while integrating ICT for ESD in the lesson?
5.	How did you assess students' understanding and provide feedback related to ESD concepts during the lesson?

## Appendix G: Ethical clearance certificate from UKZN



12 August 2024

Dr Mzwandile Wiseman Zulu (53415)  
Lulamile Zangwa (212523413)  
Mziwendoda Dzanibe (210501841)  
School of Education  
Edgewood Campus

Dear Researchers,

**Protocol reference number:** HSSREC/00006730/2024

**Project title:** Enhancing mathematics education through education for sustainable development integration and educational technologies innovations: A South African perspective

**Non-Degree**

### Approval Notification – Amendment Application

This letter serves to notify you that your application and request for an amendment received on 07 August 2024 has now been approved as follows:

- Added co-investigators

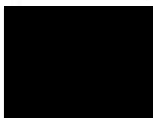
Any alterations to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form; Title of the Project, Location of the Study must be reviewed and approved through an amendment /modification prior to its implementation. In case you have further queries, please quote the above reference number.

**PLEASE NOTE:** Research data should be securely stored in the discipline/department for a period of 5 years.

HSSREC is registered with the South African National Health Research Ethics Council (REC-040414-040).

Best wishes for the successful completion of your research protocol.

Yours faithfully



.....  
Professor Dipane Hlalele (Chair)

/nng

---

Humanities & Social Sciences Research Ethics Committee  
UKZN Research Ethics Office Westville Campus, Govan Mbeki Building  
Postal Address: Private Bag X54001, Durban 4000  
Tel: +27 31 260 8350 / 4557 / 3587  
Website: <http://research.ukzn.ac.za/Research-Ethics/>

Founding Campuses: ■ Edgewood ■ Howard College ■ Medical School ■ Pietermaritzburg ■ Westville

**INSPIRING GREATNESS**

## Appendix H: Parent/ Guardian consent letter and declaration



### Informed Consent Letter to the Parent/Guardian

Dear Parent/Guardian,

I trust this letter finds you well. I am writing to seek your permission for a special classroom visit to observe and document the implementation of Education for Sustainable Development (ESD) within one of your child's mathematics lessons.

As part of my ongoing research project at the University of KwaZulu-Natal, I am focusing on enhancing mathematics education through the integration of ESD principles using ICT. I believe that your child's classroom offers a valuable opportunity to witness and learn from this innovative teaching approach.

The visit will take approximately one lesson, during which I will observe the teacher's implementation of ESD strategies. Your child's participation is entirely voluntary, and their regular class schedule will not be disrupted.

Your support is instrumental in the success of our research, and we would greatly appreciate your consent for this classroom visit. If you have any questions or concerns, please feel free to contact me directly.

I may be contacted at:

Email: 210501841@stu.ukzn.ac.za/d [REDACTED]

Cell: [REDACTED]

Thank you for your understanding and cooperation.

Best regards,

Mr. Mziwendoda Dzanibe (Researcher; UKZN).

**DECLARATION**

I, ..... [Parent/Guardian's Full Name], hereby grant permission for my child, ..... [Child's Full Name], to participate in the classroom visit as described in the letter, from Mr. Mziwendoda Dzanibe, a researcher at the University of KwaZulu-Natal. I understand that the visit will involve the observation of a mathematics lesson focused on implementing Education for Sustainable Development (ESD) principles through ICT. I acknowledge that my child's participation is voluntary, and I appreciate the opportunity for them to be part of this innovative

*Additional consent*

I understand that my child is free to withdraw from the research project at any time.

YES/NO

**PARENT/GUARDIAN'S SIGNATURE:**

**DATE:**

.....

.....

## Appendix I: Learner Consent Letter and Declaration



### Informed Consent Letter to the Learner

Dear Learner,

I hope this letter finds you all well and ready for an exciting opportunity! My name is Mr. Dzanibe, a researcher at the University of KwaZulu-Natal (UKZN). I am reaching out to share an innovative project I am working on to enhance mathematics education.

As part of my research, I am implementing Education for Sustainable Development (ESD) principles through ICT in mathematics lessons. I believe your classroom provides a fantastic setting to showcase this unique teaching approach.

I would like to invite you to participate voluntarily in a classroom visit where I will observe and document your teacher implementing ESD strategies through ICT during a mathematics lesson. The visit will take only one lesson, and your regular class schedule will not be disrupted.

Your involvement is crucial to the success of our research, and I believe you will find the experience both interesting and insightful. If you have any questions or concerns, feel free to ask your teacher or contact me directly.

I may be contacted at:

Email: 210501841@stu.ukzn.ac.za/ [REDACTED]

Cell: [REDACTED]

Looking forward to your enthusiastic participation!

Best regards,

Mr. M. Dzanibe (Researcher; UKZN)

**Declaration of Consent**

I, ..... [Learner's Full Name], voluntarily agrees to take part in the classroom visit outlined in the letter from Mr. Dzanibe, a researcher at the University of KwaZulu-Natal. I understand that the visit will entail observing a mathematics lesson emphasizing the integration of Education for Sustainable Development (ESD) principles through ICT. I affirm that my involvement is entirely of my own choice, and I am enthusiastic about being part of this innovative teaching approach.

***Additional consent***

I understand that I am free to withdraw from the research project at any time.

YES/NO

**LEARNER’S SIGNATURE:**

**DATE:**

.....

.....

## Appendix J: Permission letter from DBE



**KWAZULU-NATAL PROVINCE**  
EDUCATION  
REPUBLIC OF SOUTH AFRICA

### OFFICE OF THE HEAD OF DEPARTMENT

Private Bag X 9137, PIETERMARITZBURG, 3200  
Anton Lembede Building, 247 Burger Street, Pietermaritzburg, 3201  
Email: buyi.ntuli@kzndoe.gov.za Tel: 033 392 1051

Ref No.: 2/4/8/107

Enquiries: Mrs B. T. Ntuli

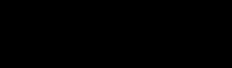
Dr Mzwandile Wiseman Zulu  
14 Marian hill Road  
1Magnolia Mews, Ashley  
**PINETOWN**  
3610

Dear Dr Zulu

#### PERMISSION TO CONDUCT RESEARCH IN THE KZN DoE INSTITUTIONS

Your application to conduct research entitled: **“ENHANCING MATHEMATICS EDUCATION THROUGH ESD INTEGRATION AND EDUCATIONAL TECHNOLOGIES INNOVATIONS: A SOUTH AFRICAN PERSPECTIVE.”**, in the KwaZulu-Natal Department of Education institutions has been approved. The conditions of the approval are as follows:

1. The researcher will make all the arrangements concerning the research and interviews.
2. The researcher must ensure that Educator and learning programmes are not interrupted.
3. Interviews are not conducted during the time of writing examinations in schools.
4. Learners, Educators, Schools and Institutions are not identifiable in any way from the results of the research.
5. A copy of this letter is submitted to District Managers, Principals and Heads of Institutions where the Intended research and interviews are to be conducted.
6. The period of investigation is limited to the period from **13 February 2024 to 31 August 2026**.
7. Your research and interviews will be limited to the schools you have proposed and approved by the Head of Department. Please note that Principals, Educators, Departmental Officials and Learners are under no obligation to participate or assist you in your investigation.
8. Should you wish to extend the period of your survey at the school(s), please contact Mrs Buyi Ntuli at the contact numbers above.
9. Upon completion of the research, a brief summary of the findings, recommendations or a full report/dissertation/thesis must be submitted to the research office of the Department. Please address it to The Office of the HOD, Private Bag X9137, Pietermaritzburg, 3200.
10. Please note that your research and interviews will be limited to schools and institutions in KwaZulu-Natal Department of Education.

  
Mr G.N. Ngcobo  
Head of Department: Education  
Date: 13 February 2024

**GROWING KWAZULU-NATAL TOGETHER**

## Appendix K: Turnitin similarity report

Mziwendoda Dzanibe Full Thesis V3....docx

### ORIGINALITY REPORT

<b>6%</b>	<b>4%</b>	<b>4%</b>	<b>1%</b>
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

### PRIMARY SOURCES

<b>1</b>	Khathutshelo Ronald Munasi. "Evaluating the Integration of Education for Sustainable Development in the Life Sciences Curriculum: A Case Study of Grade 11 Teachers in Vhembe East District", Sustainability, 2024 Publication	<1%
<b>2</b>	<a href="http://www.ajol.info">www.ajol.info</a> Internet Source	<1%
<b>3</b>	<a href="http://kipdf.com">kipdf.com</a> Internet Source	<1%
<b>4</b>	"Implications of Information and Digital Technologies for Development", Springer Science and Business Media LLC, 2024 Publication	<1%
<b>5</b>	Umesh Ramnarain, Mdutshekelwa Ndlovu. "Information and Communications Technology in STEM Education - An African Perspective", Routledge, 2023 Publication	<1%
<b>6</b>	<a href="http://wiredspace.wits.ac.za">wiredspace.wits.ac.za</a> Internet Source	<1%
<b>7</b>	Submitted to University of Wollongong Student Paper	<1%
<b>8</b>	Ramashego Shila Mphahlele, Mncedisi Christian Maphalala. "Contextualising Rural Education in South African Schools", Brill, 2023	<1%

## **Appendix L: Letter from Editor**

14 April 2025

[REDACTED]

Dear Sir / Madam

### **Declaration of language editing**

I hereby confirm that I have edited Mziwendoda Dzanibe's Master's Dissertation titled *Exploring the Integration of Education for Sustainable Development through Information and Communication Technology in Mathematics Education*. APA 7 referencing has been applied.

[REDACTED]

**Amanda Matthee**

*Text writer, translator and editor*

*MA, BA Hons, PGDip Translation, PGDip Leadership (Stell)*

*Certificate Course in Editing Academic Texts (Stell)*

[REDACTED] | [REDACTED]