

**BINDURA UNIVERSITY OF SCIENCE EDUCATION
FACULTY OF SCIENCE EDUCATION
DEPARTMENT OF CURRICULUM AND EDUCATIONAL
MANAGEMENT STUDIES**



**SCIENCE TEACHERS' PERCEPTIONS ON THE USE OF INTERACTIVE
SIMULATIONS TO FOSTER CRITICAL THINKING SKILLS: A CASE
STUDY AT BEDFORDVIEW SCIENCE CLUSTER**

BY

BIGBOY GORA

B214027B

**A RESEARCH PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS OF THE MASTER OF SCIENCE EDUCATION DEGREE IN
MEASUREMENT, ASSESSMENT & EVALUATION**

JANUARY 2024

DECLARATION

I, Gora Bigboy, hereby declared that, except for references to other people's work which have been duly acknowledged, this dissertation is the result of my own research and has neither in part nor in whole been presented in education programme.

Signed: Bigboy Gora
(Student)



Date: 01.02.24

This research work was undertaken under the supervision of Dr. Mudavanhu Y.

Signed: Dr Y Mudavanhu



Date: 01.02.24

DEDICATION

To my beloved wife Mati, whose patience and unwavering encouragement were the anchors in my stormiest days. You embraced my late nights and celebrated my triumphs as if they were your own. This dissertation bears the imprint of your selfless support, and I dedicate it to you as a token of my deepest love and appreciation.

ACKNOWLEDGEMENTS

First and foremost, my deepest respect and gratitude go to my supervisor, Dr Mudavanhu Y, whose insightful guidance and insistence on exacting scholarly standards shaped this dissertation from its inception. Your intellectual rigour and infectious enthusiasm challenged me to push beyond my limits, and your mentorship will forever be etched in the foundation of my academic journey. My friend and brother, Percy Zenda, your unwavering support and unfettered belief in my potential energised me and fuelled my resolve through countless late nights and moments of doubt. Finally, to my incredible Physics students class of 2024, your inquisitive minds and thirst for knowledge have been a constant source of inspiration. Witnessing you embark on your own academic journeys has been one of the greatest rewards of this process. This dissertation is dedicated to you, the future scholars and researchers who carry the torch of inquiry, forever reminding me of the power of knowledge to shape the world.

ABSTRACT

This qualitative study, informed by a naturalist methodology situated in the Constructivist (Interpretivist) paradigm, adopted the Technological Pedagogical and Content (TPACK) theoretical framework to explore science teachers' perceptions on using interactive simulations such as the Physics Education Technology (PhET) and Labster, for virtual labs, to nurture critical thinking skills in South African independent schools. For this study, critical thinking was defined as the intellectually disciplined process of actively and skilfully conceptualising, applying, analysing, synthesising, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication, as a guide to belief, drawing conclusions and taking appropriate decisions and actions.

Surveys and interviews with eight science teachers from seven schools revealed a multifaceted interplay of factors influencing simulation use. Teacher characteristics, particularly Technological, Pedagogical, and Content Knowledge (TPACK), significantly impacted adoption of simulations. While 70% of teachers recognized the potential of simulations, 45% expressed anxiety about aligning them with curriculum goals and a lack of clear objectives for critical thinking development. School environment also played a crucial role. Reliable hardware, robust software with strong connectivity, and readily accessible technical support were essential, but 80% of teachers feared potential technical disruptions. Furthermore, the perceived value of interactive simulations (60% viewed them as highly beneficial) and student needs, influenced utilisation. Assessment remained a concern. Existing methods did not adequately evaluate critical thinking fostered by simulations. Teachers desired science-specific resources, collaboration opportunities, and ongoing professional development focused on maximising interactive simulations' potential.

The study aligns with existing literature highlighting the importance of TPACK and addressing teacher anxieties for successful technology integration. However, it emphasizes the additional need for curriculum-aligned, assessment-driven professional development programs specifically focused on fostering critical thinking through simulations. Further research in each identified area of TPACK, curriculum alignment, and assessment is crucial to facilitate wider, informed and impactful technology integration within South African science classrooms, ultimately empowering students with critical thinking skills.

TABLE OF CONTENTS

DECLARATION	II
DEDICATION	III
ACKNOWLEDGEMENTS	III
ABSTRACT	VI
1.1 INTRODUCTION:	1
1.4 STATEMENT OF THE PROBLEM	3
1.5 RESEARCH QUESTIONS:	5
1.5.1 MAIN RESEARCH QUESTION	5
1.5.2 SUB-RESEARCH QUESTIONS	5
1.6 SIGNIFICANCE OF THE STUDY	1
1.7 ASSUMPTIONS OF THE STUDY	1
1.8 DELIMITATIONS	1
1.9 LIMITATIONS	2
1.10 DEFINITION OF KEY TERMS	2
1.11 SUMMARY OF CHAPTER 1	3
CHAPTER 2: REVIEW OF RELATED LITERATURE	4
2.1 INTRODUCTION	4
2.2 THEORETICAL FRAMEWORK: TECHNOLOGICAL PEDAGOGICAL AND CONTENT KNOWLEDGE (TPACK)	5
2.3 THEORIES OF ‘PERCEPTIONS ON THE USE OF TECHNOLOGY’	7
2.3.1 THEORY OF PLANNED BEHAVIOUR (TPB)	8
2.3.2 TECHNOLOGY ACCEPTANCE MODEL (TAM)	10
2.3.3 UNIFIED THEORY OF ACCEPTANCE OF USE OF TECHNOLOGY: VENKATESH, MORRIS, DAVIS AND DAVIS(2003).....	11
2.4 SCIENCE TEACHERS’ VIEWS ON THE USE OF INTERACTIVE SIMULATIONS TO FOSTER CRITICAL THINKING SKILLS. 13	
2.4.1 SIMULATIONS BASED LEARNING (SBL) AS A LEARNER-CENTRED PEDAGOGY.....	13
2.4.2 THE LINK BETWEEN SIMULATIONS BASED LEARNING (SBL) AND CRITICAL THINKING SKILLS	15
2.5 METHODS USED BY SCIENCE TEACHERS TO ASSESS CRITICAL THINKING SKILLS	18
2.6 WHAT SCHOOLS CAN DO TO HELP SCIENCE TEACHERS USE INTERACTIVE SIMULATIONS TO FOSTER CRITICAL THINKING SKILLS.	19
2.7 SUMMARY OF CHAPTER 2	21
CHAPTER 3 RESEARCH METHODOLOGY	22
3.1 INTRODUCTION	22
3.2 RESEARCH DESIGN	22
3.2.2 THE RESEARCH APPROACH.....	23
3.2.3 RESEARCH STRATEGY	24
3.3 POPULATION AND SAMPLE.....	25
3.3.1 THE PARTICIPANTS.....	25
3.4 DATA COLLECTION	25
3.4.1 RESEARCH INSTRUMENTS.....	26
3.4.2 DATA GATHERING TECHNIQUES	26
3.5 DATA ANALYSIS	27
3.6 REFLEXIVITY	27
3.7 VERIFICATION OF QUALITATIVE RESULTS	27

3.8	ETHICAL CONSIDERATIONS.....	28
3.9	PRESENTATION OF FINDINGS.....	28
3.10	SUMMARY OF CHAPTER 3	29

CHAPTER 4 RESULTS PRESENTATION, ANALYSIS AND DISCUSSION 30

4.1	INTRODUCTION.....	30
4.2	BIOGRAPHICAL DATA OF RESPONDENTS.....	31
4.3	FACTORS THAT INFLUENCE THE USE OF INTERACTIVE SIMULATIONS BY SCIENCE TEACHERS.	32
4.4	PERCEPTIONS OF SCIENCE TEACHERS ON THE USE OF INTERACTIVE SIMULATIONS TO FOSTER CRITICAL THINKING SKILLS.	48
	TABLE 4.4 SCIENCE TEACHERS' PERCEPTIONS ON USING INTERACTIVE SIMULATIONS FOR CRITICAL THINKING SKILLS.....	50
4.5	METHODS USED BY SCIENCE TEACHERS TO ASSESS CRITICAL THINKING SKILLS	61
	TABLE 4.6: THEMES ON ASSESSMENT METHODS FOR CRITICAL THINKING SKILLS.....	63
4.6	WHAT SCHOOLS CAN DO TO HELP SCIENCE TEACHERS TO USE INTERACTIVE SIMULATIONS TO FOSTER CRITICAL THINKING.	70
4.7	SUMMARY OF CHAPTER 4	78

CHAPTER 5: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS 80

5.1	INTRODUCTION.....	80
5.2	RESEARCH SUMMARY	80
5.3	RESEARCH CONCLUSIONS.....	80
5.4.1	RESEARCH RECOMMENDATIONS.....	81
5.4.2	REFERENCES	85

	APPENDIX 1: INTRODUCTORY LETTER FROM BUSE	96
	APPENDIX 2: APPROVAL LETTERS	97
	APPENDIX 3: INSTRUMENT 1 - INTERVIEW SURVEY	98
	APPENDIX 4: INSTRUMENT 2- INTERVIEW QUESTIONS – SEMI STRUCTURED	103
	APPENDIX 5: TEACHER INVITATION TO PARTICIPATE IN THE RESEARCH AND CONSENT FORM	107

CHAPTER 1: INTRODUCTION TO THE STUDY

1.1 Introduction:

This chapter lays the groundwork for the study into science teachers' perceptions on the use of interactive simulations to foster critical thinking skills in South African independent schools. It begins by providing context through a review of the background to the study, highlighting the growing importance of technology integration in science education and the potential benefits of interactive simulations for developing critical thinking skills. The purpose of the study is clearly outlined, specifying the research objectives and the specific focus on teacher perceptions. The chapter then articulates the statement of the problem, thereby identifying the existing gap in knowledge by critically examining current research on teacher technology integration and highlighting areas where further exploration is needed. This will pave the way for the introduction of the specific research questions that guided this study. The significance of this research is also addressed. This section will emphasise the importance of understanding teacher perceptions and the potential impact of the findings on improving science education through technology integration in general and interactive simulations in particular. Furthermore, the chapter will explicitly state the assumptions of the study. This section clarifies any underlying beliefs about the research context or participants. To ensure clarity and focus, the delimitations of the study will be outlined. This section will define the boundaries of the research by specifying the participants of the study, the timeframe, and any specific limitations on the scope of the study. The chapter will also address the limitations of the research design and methodology. This section acknowledges any potential weaknesses or constraints that may influence the findings of the study. The chapter concludes with a clear definition of key terms. This section ensures a shared understanding of critical terms used throughout this research, such as "interactive simulations" and "critical thinking skills."

1.2 Background to the study

The 21st century has witnessed a growing emphasis on fostering critical thinking skills in educational settings (Almulla, 2018). This focus coincides with the emergence of interactive simulations as a powerful tool for science education. Interactive simulations offer a dynamic and engaging learning environment where students can manipulate variables, observe phenomena, and analyse data in a safe and controlled setting

(Langbeheim and Levy, 2019). Research suggests that interactive simulations can lead to effective and deep learning gains (Matute-Vallejo and Melero-Polo, 2019; Sanina, Kutergina, and Balashov, 2020). By encouraging students to apply their knowledge to real-world problems through scenario-based learning, simulations can foster critical thinking, problem-solving, and analytical skills (Sanina, Kutergina, and Balashov, 2020). This potential for improved learning outcomes aligns with the South African Department of Education's policy on integrating Information and Communication Technologies (ICTs) in education (Department of Education, 2004). However, research suggests a gap between policy and practice, with a lack of sustained ICT integration in South African classrooms (Amory, 2015). Factors like teacher proficiency, infrastructure availability, and support systems may be hindering wider adoption (Amory, 2015). Understanding teacher perceptions and challenges regarding technology integration is crucial. Studies examining teachers' general technology adoption reveal factors such as teacher beliefs, pedagogical skills, and access to resources that can influence their use of technology (Ertmer and Ottenbreit-Leftwich, 2010; Yildiz, 2011). Specifically, regarding interactive simulations, research suggests that teachers' perceptions of their effectiveness, alignment with curriculum goals, and ease of use can influence their adoption (Smetana and Lawless, 2010).

Critical thinking in science education involves the ability to analyse evidence, evaluate arguments, and draw sound conclusions based on scientific reasoning (Halpern, 1998). Different models exist to define and assess critical thinking skills (Facione, 2000; Ennis, 1989). Some studies explore teachers' understanding and assessment of critical thinking skills. For example, Facione (1998) found that while teachers valued critical thinking, they often lacked explicit strategies for fostering it in their classrooms. While research supports the benefits of interactive simulations for learning, the specific impact on critical thinking skills requires further investigation. Some studies show promise. For instance, de Jong, van Joolingen, and Linn (2013) found that students using simulations in a science inquiry setting demonstrated improved critical thinking abilities. However, more research is needed to explore the effectiveness of different simulation designs and instructional approaches for fostering critical thinking in science education (de Jong et al., 2013). It is against this background that this research study sought to investigate the perceptions of science teachers at the Bedfordview science cluster, on the use of interactive simulations to foster critical thinking skills. This study provided a wide angle view of the various factors such as teacher skills,

beliefs, learner characteristics, school culture and technology infrastructure, opportunities for professional development, understanding of critical thinking skills, teaching and assessment of critical thinking skills, as viewed through the various lenses of the participants according to their lived realities.

1.3 Purpose of the study

The purpose of this research is to establish to what extent, if at all, high school Science educators in South African schools consider interactive simulations to be effective instructional tools in fostering Critical Thinking Skills in their learners. More pertinent is how they position the simulations in their lessons based on how they frame their lesson objectives to foster critical thinking skills. The study will also seek to establish what tools or mechanisms the educators use to assess the development of their learners' critical thinking skills. In the same vein, the study also seeks to establish to what extent the science teachers themselves feel confident about their own critical thinking dispositions and their perceived barriers to effective and consistent integration of ICT in their classrooms in general.

1.4 Statement of the problem

From personal experience and interaction with peers in the community of practice in South Africa, the typical Physical Sciences educator is preoccupied with teaching content with a view to completing the syllabus timeously in order to afford the students ample time to revise and be adequately prepared for the examinations. Thus the process of learning is largely characterised by mechanical absorption of content and the regurgitation of the same when assessments are given. This creates an atmosphere deficient of critical thinking opportunities. Most of the teachers are themselves products of the same system and hence it can reasonably be surmised that their methodologies may be devoid of critical thinking objectives. The thoughtful incorporation of strategic methodologies for critical thinking is therefore peripheral and far in-between. Paul (1992) lends further credence to the writer's experiential claims when he argues that typical school instruction does not encourage the development of higher-order thinking skills like critical thinking and that knowledge is coterminous with thinking, especially good or critical thinking. As several studies point out (Oliveira and Rodrigues, 2004; Rivard, 2004), science classrooms are still strongly teacher directed, that is, the teaching and learning model used is mainly the transmission model that does not foster

critical thinking. Cultural backgrounds in South Africa tend to spawn dispositions that dowse the spirit of interrogation of information and expression of a benignly sceptical mind. It is atypical of students in a South African classroom to openly challenge the knowledge that the teacher presents. This is due to the dearth of authentic learning experiences. Physical Science is a learning domain not widely known about, let alone understood, by the majority of the South African society. There is also a fine line between questioning sparked by genuine curiosity and that which is blatant disrespect for authority and seniors. Hence a combination of learner and teacher dispositions towards questioning, and the need for curriculum coverage make for a very bleak prognosis for the accommodation of critical thinking in the instructional process in a South African Physical Science lesson. Physical Science content is perceived as inherently abstract and therefore difficult. Critical thinking may potentially be conflated with the perceived difficult nature of the subject. Equally noteworthy is the fact that critical thinking is not solely the exhibition of rarefied cognitive abilities bordering on genius. Critical thinking skills can be acquired and deployed at any age or level of learning.

Critical thinking skills are essential for success in science, enabling students to analyse evidence, evaluate arguments, and draw sound conclusions (Halpern, 1998). Despite national policies promoting ICT integration and the potential of interactive simulations to foster critical thinking (Department of Education, 2004), many South African students across various grade levels struggle with these skills, hindering their achievement in science subjects. Research suggests a persistent gap between South African ICT integration policies and classroom practices (Amory, 2015). Studies highlight a lack of ICT integration within school cultures (Amory, 2015) and negative teacher perceptions toward technology (Msila, 2015; Ndibalema, 2014). These negative views may stem from a lack of understanding about the pedagogical value of technology (Sherman & Howard, 2012).

This study specifically addressed the under-researched area of science educators' views and experiences with interactive simulations for fostering critical thinking in South African Independent schools in the Bedfordview cluster. The focus was on secondary science teachers, grades 8-12. Critical thinking skills were defined within the context of scientific inquiry, encompassing analysis, evaluation, and problem-solving specific to scientific phenomena.

The study acknowledges limitations such as the availability and quality of interactive simulations accessible to the participants in their respective schools. The validity and reliability of data collection instruments might not have been sufficient to exhaustively capture the full extent of the teachers' nuanced perceptions on the use of interactive simulations and their effectiveness in fostering critical thinking skills.. Furthermore, the generalisability of the findings may be limited due to the fact that the schools in the Bedfordview cluster are all predominantly affluent and top tier schools. It is reasonable to surmise that the findings could potentially have been significantly worse had the study been conducted elsewhere, where the socio-economic circumstances are worse. However, the study aimed to contribute valuable insights into the under-explored area of teacher perceptions and practices regarding interactive simulations for critical thinking development in South African science education and it is reasonable to suggest that the findings would be transferable to schools in other parts of South Africa with comparable resources.

1.5 Research Questions:

1.5.1 Main research question

How do Physical Science teachers' perceptions shape the use of PhET interactive simulations for fostering critical thinking?

1.5.2 Sub-research questions

- What are the factors that influence the use of interactive simulations by science teachers to foster critical thinking skills?
- What are the perceptions of science teachers on the use of interactive simulations to foster critical thinking skills?
- What are the methods used by science teachers to assess specific critical thinking skills developed through the use of interactive simulations?
- What can schools do to help science teachers use interactive simulations to foster critical thinking?

1.6 Significance of the Study

The study will be used to build a body of knowledge for future studies and research as a reference. The results of the research will also inform practising educators on the efficacy or lack of the same, of Interactive Simulations and hence potentially lead to improved instructional practice in the teaching of Physical Sciences and by extension, improvement of the results of the students. Simulation scenarios provide experiences for students to improve communication and teamwork, and develop skills such as delegation, prioritization, and critical thinking (Rockstraw & Wilson, 2012). The use of simulations is also helpful in substituting for lack of laboratory equipment and also eliminate risks associated with breakages and possible injury associated with the manipulation of equipment. The study will potentially inform policy on training and professional development. By highlighting the instructional value of computer generated Interactive Simulations, more innovative ways to avail such digital tools free of internet connectivity could be devised for greater reach to economically marginalised communities such as rural areas and farming communities. The study could serve to generally spur the migration from traditional teaching tools to 21st Century digital tools more designed for competence based education whose overarching purpose is to impart and nurture skills such as critical thinking, problem solving, communication, collaboration, creativity and digital literacy to name a few, as opposed to mechanical absorption of facts without any veneer of academic scepticism. It is also hoped that the study will provide evidence for the need for educators to be intentional and reflective in their selection of digital tools which are fit for purpose, and whose planning is in-depth and inclusive, simultaneously catering to both the content and habits of mind by effectively harnessing the technology of interactive simulations and other educational digital tools as well. The study could motivate educators and technology experts to come up with better, cheaper and more readily accessible Interactive Simulations that educators without any significant computer background can confidently use. The study also seeks to provoke science educators to engage in metacognitive regulation, constantly challenging their own critical thinking capabilities in order to maximally assist the learners they teach.

1.7 Assumptions of the study

The most basic assumption of this study is that the proposed treatment, that is, the use of PhET Interactive Simulations in the teaching of Physical sciences, has an effect on the development of critical thinking skills of the learners.

The study makes the following further assumptions:

1.7.1 The responses provided by the respondents are honest

The honesty and trustworthiness of the responses provided by participants of the research cannot be over emphasised. The validity and reliability of the findings are premised on the assumption that the results are a product of credible, robust and transparent process and can therefore be reproduced.

1.7.2 The participants consisted of respondents of similar or comparable characteristics and therefore there were no outliers

The participants were of comparable academic level and, their schools were, to a great extent, comparable in terms of technological resources

1.8 Delimitations

The schools that are the subject of this study are seven Independent (Private) High Schools located in Johannesburg East, South Africa, that offer the Independent Examinations Board (ieb) examinations. Two of the schools have two Physical Science teachers while the remaining five have one teacher per school, making a total of nine teachers, of which only eight participated in this study. These schools offer examinations based on the Curriculum Assessment Policy Statement (CAPS), which is the overarching national curriculum guideline for all schools, Private as well as Public schools.

The choice of Physical Science and the Photoelectric Effect in particular as the subject of study is informed by the fact that it is the researcher's area of specialisation and hence there are greater chances of making more informed analyses and learning from the community of practice while simultaneously controlling the population to avoid an onerously large sample. Due to limited financial resources, all the schools for this study are based in Johannesburg East and will be chosen using non probability Convenience

sampling. The study will be carried out over a period of four months due to degree course- imposed time constraints. The study will not cover issues to do with classroom management and or general teacher competences.

1.9 Limitations

Due to lack of similar documented research within the same sample group, the study had no local frame of reference for comparison and triangulation of data. Triangulation refers to the use of multiple methods or data sources in qualitative research to develop a comprehensive understanding of phenomena (Patton, 1999). Triangulation also has been viewed as a qualitative research strategy to test validity through the convergence of information from different sources. However, the data from the surveys and the interviews for the seven schools was triangulated in search of common threads or patterns. Due to time and financial constraints, the study was limited to seven schools and was completed within a period of four months. Due to the qualitative nature of the study conducted, generalisability was not a factor to consider.

1.10 Definition of key terms

The following definitions are provided to ensure uniformity and understanding of these terms as used in the study. Critical thinking is the process of purposeful, self-regulatory judgment. This process gives reasoned consideration to evidence, contexts, conceptualizations, methods, and criteria (Facione, 1990). Put another way, critical thinking is a habit of mind that seeks logical justification before accepting a position, argument or material presented. Chance(1986) suggests that critical thinking is the ability to analyse facts, generate and organise ideas, defend opinions, make comparisons, draw inferences, evaluate arguments and solve problems. For this study, critical thinking was defined as the intellectually disciplined process of actively and skilfully conceptualising, applying, analysing, synthesising, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication, as a guide to belief and action. Scriven, Beaubien and Baker (2004) define an interactive simulation as a tool that reproduces the real-life characteristics of an event or situation. Similarly, Cook, Brydges, Zendejas, Hamstra and Hatala (2013) stated that an interactive simulation is an educational tool or device with which the learner physically interacts to mimic real life. Furthermore, Heitzmann, Seidel, Opitz, Hetmanek, Wecker, Fischer and Ufer (2019) define interactive

simulation as interaction with a real or virtual object, device, or person and the opportunity to alter the flow of this interaction with the decisions and actions made by learners. Interactive simulation as used in this study refers to computer based or computer generated programme that is a representation or model of an authentic environment and is capable of responding to the inputs of the learner by giving feedback in real time and so provides a rich and learner centred pedagogy.

1.11 Summary of chapter 1

Chapter 1 established the foundation of the study by bringing into sharp focus the research gap and the relevant research questions. Key terms were defined as operationalised in the study. Chapter 2 will examine literature related to the study which was reviewed in order to gain insights into past and contemporary research relevant to the study. Chapter 3 will focus on the methodology which was adopted for this study. The choice of instruments for data collection, appendices 3, survey form and 4, interview questions, will be described and justified. Ethical considerations that were taken will be discussed and appendix 5, the ‘informed consent’ form which was used will be presented. Chapter 4 will give details of the presentation , analysis and discussion of results of the study that were obtained. Chapter 5 will give the summary, conclusion and recommendations of the study.

CHAPTER 2: REVIEW OF RELATED LITERATURE

2.1 Introduction

The high level of abstraction in physical sciences can hinder conceptual understanding, a crucial foundation for critical thinking. Traditional teaching methods often fail to address this challenge. This chapter explores how interactive simulations, a promising educational technology, can be leveraged to cultivate critical thinking skills in science learners. However, effectively integrating technology into the classroom requires a strong theoretical foundation.

This chapter begins by establishing the Technological Pedagogical and Content Knowledge (TPACK) framework as the theoretical lens for understanding the successful integration of interactive simulations. TPACK emphasizes the interplay between content knowledge, pedagogical knowledge, and technological knowledge for effective teaching with technology.

Following the theoretical grounding, the chapter examines existing literature on the limitations of traditional teaching methods and the importance of conceptual understanding for critical thinking development. Then, it explores the concept of critical thinking and its various definitions. Next, it delves into the affordances of interactive simulations for science education, highlighting their potential to enhance learner engagement and promote active learning strategies. The chapter then investigates the connection between these features of interactive simulations and the development of critical thinking skills.

To gain insights into teacher perceptions and practices, the chapter explores relevant theories on the factors influencing technology adoption in education. These theories will illuminate the reasons behind teachers' decisions to use or not to use interactive simulations.

Finally, the chapter explores how schools can support science teachers in effectively integrating interactive simulations into their instruction. This section will provide practical recommendations for fostering a culture of innovation and technology adoption within educational institutions.

By critically examining the literature, exploring teacher perspectives, and grounding the discussion in a robust theoretical framework, this chapter aims to contribute to a deeper understanding of how interactive simulations can be harnessed to cultivate critical thinking skills in science education.

2.2 Theoretical Framework: Technological Pedagogical and Content Knowledge (TPACK)

Teaching and learning are essentially two sides of the same coin, ‘what’ and ‘how’ educators teacher has a direct effect on ‘what’ and ‘how’ learners learn. It is therefore instructive to identify an appropriate conceptual framework upon which the study hinges. A conceptual framework is the document that “explains, either graphically or in narrative form, the main things to be studied and the key factors, concepts, or variables; and the presumed relationships among them”, Miles and Huberman (1994:18). Rivitch and Riggan (2012), define a conceptual framework as an argument why the topic one wishes to study matters, why the means proposed to study it are appropriate and rigorous enough, and acts as a guide that situates specific questions in strategies to be used in exploring the phenomenon or phenomena being researched. A conceptual framework ties together the concepts, beliefs, expectations, and assumptions that support and inform the course of the research study. For this study, the Technological Pedagogical and Content Knowledge (TPACK) model by Mishra and Koehler(2006) will be the underpinning theoretical framework.

2.2.1 Technological Pedagogical and Content Knowledge (TPACK) model

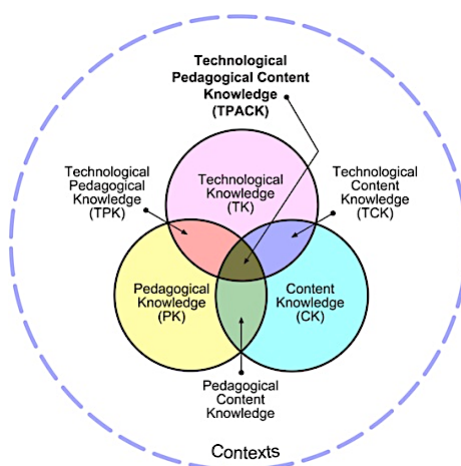


Figure 2.1 TPACK framework. <https://www.frontiersin.org/articles/10.3389/feduc.2022.1033895/full>

The Technological Pedagogical and Content Knowledge (TPACK) model is a framework that emphasises three types of knowledge which, when harnessed together or in various combinations, can transform the learning space to deliver outcomes in a dynamic and impactful manner. These are: Content knowledge (CK). This refers to the teacher's own domain specific knowledge or what is being taught. As a Physics teacher, content knowledge refers to one's mastery of the science subject matter and the particular content or concepts for the lesson. This may also include the domain's best practices as this has a bearing on the choice of instructional tools and pedagogical approaches to be adopted. Content knowledge naturally differs according to grade (Mishra and Koehler, 2006). Pedagogical Knowledge (PK) refers to the teacher's knowledge of the methods and best practices, processes, applicable to teaching and learning. (PK) places particular emphasis on the purpose, values, and aims of education, including the understanding of student learning styles, classroom management skills, lesson planning, and assessments for the specific learning area, in this case science (Mishra and Koehler, 2006). Technological Knowledge (TK) refers to the teacher's knowledge of, and ability to use, various technologies, technological tools, and associated resources. (TK) is preoccupied with the effective integration of technology in the classroom, considering its possibilities for a specific subject area or lesson, recognising when it will assist or impede learning, and continually learning and adapting to new technology offerings (Mishra and Koehler, 2006). The above three types of knowledge overlap to produce four other related types of knowledge as facets of the framework. These are Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK) and Technological, Pedagogical and Content Knowledge TPACK. Pedagogical Content Knowledge is the teacher's knowledge of the subject matter and how to deliver it in a manner that results in effective learning, including the choice of appropriate assessments, feedback and reporting of outcomes. PCK places emphasis on promoting learning and the connection between pedagogy and assessment practices. PCK varies with level and the particular content thereby placing a demand on teachers to be intentional in their choice of teaching practices. Technological Content Knowledge (TCK) is the teacher's understanding of how technology and content can both influence each other. TCK involves understanding how best the subject matter can be communicated using different educational technology tools, and choosing specific tools that might be best suited for specific subject matter or classrooms. Technological Pedagogical Knowledge (TPK) is the teacher's understanding of how particular

technologies can change both the teaching and learning experiences by introducing new pedagogical advantages and constraints. TPK focuses on how such tools can be used alongside pedagogy in ways that are appropriate to the subject and the execution of the lesson at hand. The Technological Pedagogical and Content Knowledge TPACK is the ultimate interplay among the three main knowledge types, namely content, pedagogical and technological knowledges, to create an effective basis for teaching using educational technology. Teachers can maximally exploit the TPACK framework by realising that technology can be used to effectively represent concepts being taught, pedagogical techniques can communicate content in various ways using technology, certain content concepts require particular skills levels that technology can enhance and educational technology can effectively be used to assist learners in their development of new knowledge.

A robust deployment of ICTs in the classroom therefore entails appreciation of the complimentary nature among content, pedagogy and the emerging educational technology. The teacher has the task of adopting and adapting the TPACK framework's dimensions to the unique contexts of schools, classrooms, and cultures. The framework allows for flexibility to accommodate the individual teacher's pedagogical idiosyncrasies, the grade level and the demographics of the learning space. The framework can be particularly insightful in answering the research questions of the study: the perceptions of science teachers on the use of interactive simulations to foster critical thinking skills, sub-research questions, whether or not interactive simulations foster critical thinking skills in students as perceived by science teachers, the methods used by science teachers to assess the development of critical thinking skills, and how schools can assist science teachers to use interactive simulations to foster critical thinking skills. A combination of the technological proficiency of the teacher and availability of infrastructure, the pedagogical know how of the teacher and their content mastery, all come together in one way or another in illuminating the area of this study. The conceptual framework is therefore adequate for this study.

2.3 Theories of 'perceptions on the use of technology'

In order to gain insights into the factors that influence science teachers' use of interactive simulations, it worthwhile exploring some of the well-established theories that purport to explain perceptions on the use of technology. Many scholars claim in their research, that the successful implementation of new instructional technologies,

such as interactive simulations, is closely related to the attitudes of the teachers (Fernández-Batanero, Díaz-García, and Álvarez-García, 2021). In the same vein, Hew and Brush (2007), Nyaumwe (2006), and Albion (2001) also point teachers' attitudes and beliefs as the major impediments to effective use of technology for instruction. A significant number of educators still resist the use of technology in the classroom or they view the implementation of technology in the classroom negatively (Kaban and Ergul, 2020; Istenic, Fazlic, and Hasagic, 2021). They prefer to continue beating the same age-old path of traditional pedagogy which they perceive to be less prone to negative outcomes (Tallvid, 2016). The lack of sufficient training in the use of these technologies further fuels the perceived burden (Zimmerman, 2006). "The beliefs and values that teachers hold drive many of the choices they make in the classroom" (Cuban, 2001:169). Cuban (2001) further argues that beliefs influence what and how teachers choose to teach and what innovations they endorse or reject. In concurrence with Cuban, (Munby, 1984:28) states that "teachers' beliefs and principles are contextually significant to the implementation of innovations". The perceptions of educators therefore need to be taken in context, which can evolve over time. Human behaviour is a complex domain and measurement of perceptions therefore, cannot be linear. A matrix of factors come into play. Literature is awash with models that seek to provide some basis on observed or perceived human behaviours. The following models are deemed relevant to this study and therefore merit some elaborate mention.

2.3.1 Theory of Planned Behaviour (TPB)

The Theory of Planned Behaviour (TPB) is a modification and an extension of the Theory of Reasoned Action (TRA) (Ajzen & Fishbein 1980). The overarching premise in both models is that individuals make reasoned decisions to behave in a particular way by evaluating the information available to them. The behaviour is an expression of the individual's intention to do so, and the intention is influenced by the perceived value the individual places on the behaviour, the ease with which the behaviour can be executed as well as the views of others. According to the TPB, the factors that directly influence intentions to engage in a particular behaviour include the person's attitudes toward the behaviour, the person's perception of subjective group norms concerning the behaviour, that is, beliefs about others' attitudes toward a behaviour, and the extent to which the person perceives him- or herself to have control concerning the behaviour (Ajzen, 2020). The perceptions of the educator on the

effectiveness of interactive simulations need therefore to be explained in terms of the individual's disposition and idiosyncrasies, considering their lived reality.

Graphical depiction of the theory of planned behaviour (Ajzen, 2019b).

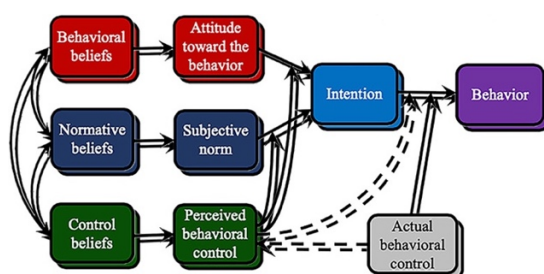


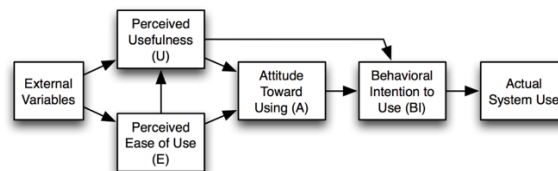
Fig 2.2 Theory of Planned Behaviour. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7909498/>

In the context of use of interactive simulations to foster critical thinking skills, the above factors: Attitudes, Subjective norms and Perceived behavioural control can be explained as follows: Attitudes toward the effective and proficient use of simulations in in the teaching of the science content, as well as honing the desired critical thinking skills. Subjective norms are social pressures and perceived expectations of both colleagues and students on one's capability and projection as being tech savvy. Perceived behavioural control would relate to how confident one is in the effective handling of technology, interactive simulations in this case. How proficient one rates oneself in terms of technological literacy and the potential fall-out should there a disjuncture between the taught content and the interactive simulation concepts. The more positive one feels about all three factors, the greater the odds of them adopting the use of interactive simulations and effectively using them to nurture critical thinking skills. The TPB highlights the psychological factors influencing a teacher's decision to integrate interactive simulations. It explains that a teacher's attitudes towards their effectiveness in teaching science content and fostering critical thinking, social pressures from colleagues and students regarding technology use, and their confidence in handling the technology, perceived behavioural control, all influence their adoption and successful implementation of interactive simulations. Therefore, understanding these factors can help explain some of the perceptions of the teachers regarding the use of interactive simulations to foster critical thinking skills.

2.3.2 Technology Acceptance Model (TAM)

According to the Technology Acceptance (TAM) Model (Davis, 1989), there are two factors that determine whether a computer system will be accepted by its potential users: Perceived usefulness, and Perceived ease of use. It is interesting to note that both factors are functions of 'perception'.

Fig 2.3 The Technology Acceptance Model (Davis, 1989)



<https://www.researchgate.net/figure/Illustration-of-the-Technology-Acceptance-Model-TAM>

The decision to perform any given task is motivated by the perceived benefit of any such action relative to the ease or difficulty of performing such a task (Johnson & Payne, 1985). The use of technological tools is thus determined by an evaluation of the trade-off between the perceived usefulness of the system and the perceived difficulty of using it (Davis, 1989). The perceived usefulness is defined as the individual's perception of the extent to which the use of a given technology improves performance. This is in conformity with the concept of outcome judgement, that is, the individual's expectation of a favourable outcome will trigger the behaviour (Bandura, 1982). Perceived usefulness is given context based on evidence confirming the favourable effect of using the technology tool in producing desired goals (Robey, 1979). Perceived ease of use is the relative simplicity of use or minimal demand of effort on the use of the technology tool (Davis, 1989). The model is premised on the self-efficacy concept, in which one predicts how well they can potentially execute some actions in the performance of a task at hand (Davis, 1989; Bandura, 1982). Perceived ease of use is defined as the degree to which individuals find the innovation difficult to understand and use (Mahajan, 2010). As with the Theory of Planned Behaviour, the perceptions of teachers on the effectiveness of interactive simulations will very much be influenced by a number of beliefs and exogenous factors. The TAM was criticised for its limited number of actionable guidelines to practitioners resulting in Lee, Kozar and Larsen (2003), Venkatesh and Bala (2008) combining the initial conditions of perceived

usefulness and perceived ease of use in a single model. They then investigated the relationship between the antecedents and perception variables to exclude cross-over effects. This added clarity to the literature, which had been inconsistent in terms of the predictors of the two perception factors (Venkatesh & Davis, 2000). This gave rise to the Unified Theory of Acceptance of Use of Technology (UTAUT) Model.

2.3.3 Unified Theory of Acceptance of Use of Technology: Venkatesh, Morris, Davis and Davis(2003)

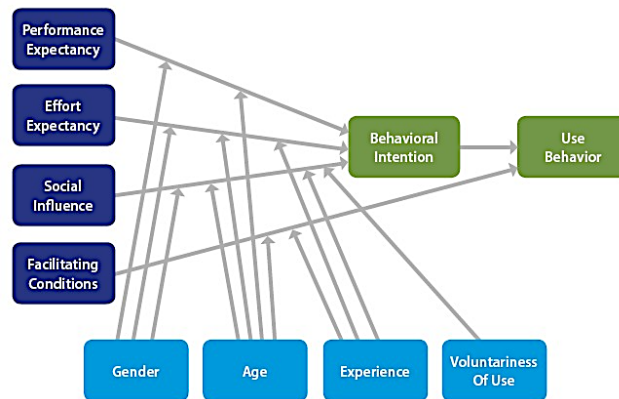


Fig 2.4: The UTAUT Model. <https://www.ncbi.nlm.nih.gov/books/NBK481588/figure/c3.f2/>

In this context, Performance expectancy is defined as the degree to which using interactive simulations will provide benefits to both educators and learners in the teaching-learning process; effort expectancy is the degree of ease associated with teachers' and learners' use of interactive simulations; social influence is the extent to which teachers perceive that learners, fellow teachers and superiors believe they should use interactive simulations in their lessons; and facilitating conditions refer to teachers' perceptions of the resources and support available to use interactive simulations (Brown and Venkatesh 2005). The above four constructs of UTAUT are believed to be the pillars that influence technology assimilation and associated specific behaviours such as using interactive simulations as instructional tools. The other variables, namely age, gender and experience, are meant to moderate the various relationships within UTAUT. The UTAUT model has been extended to include three more constructs: hedonic motivation, price value, and experience and habit.

Hedonic Motivation

Hedonic motivation has been defined as the fun/pleasure or enjoyment derived from using a technology, and it has been shown to play an important role in determining

technology acceptance and use (Brown and Venkatesh 2005). This perceived enjoyment has been found to be a key factor in the acceptance and effective use of technology such interactive simulations (van der Heijden 2004).

Price Value

The cost and pricing of technology infrastructure undoubtedly plays a significant role in the ultimate use of technology. For instance, there is evidence that the popularity of short messaging services (SMS) in China is due to the low pricing of SMS relative to other types of functions. In this context, price value is defined as teachers' cognitive trade-off between the perceived benefits of using interactive simulations and the monetary cost for using them (Dodds et al. 1991). The price value is positive when the benefits of using a technology are perceived to outstrip the monetary value and has potentially positive impact on the intention.

Experience and Habit

Habit has been defined as the extent to which individuals tend to perform behaviours automatically because of learning (Limayem et al. 2007), while Kim et al. (2005) equate habit with automaticity. It is the extent to which one is inclined to perform a certain task without making a conscious decision to do so. Ajzen and Fishbein (2005) noted that feedback from prior experiences influence various beliefs and, consequently, future behavioural performance. What educators have been exposed to determines how they embrace new innovations such as interactive simulations. The extended UTAUT model is generally referred to as UTAUT2.

A comprehensive understanding of the factors that influence the use of interactive simulations by science teachers in a South African context, as anywhere else in the world, involves considering technological competence, perceived pedagogical value, curriculum alignment, resource availability, and teachers' attitudes and beliefs. The perceptions of individual teachers will most naturally lean towards the feedback to their unique lived experiences. This study will seek to ascertain any particular themes or common threads that can inform theory and practice going forward. Understanding what the science teachers think and feel is critical, because the successful attainment of educational outcomes of any curriculum depends on its effective implementation.

2.4 Science teachers' views on the use of Interactive Simulations to foster critical thinking skills.

Section 4.1 provided a comprehensive overview of Simulations-Based Learning (SBL) and its potential to foster critical thinking skills. The characteristics of critical thinking skills and how interactive simulations align with these characteristics to promote critical thinking development were explored. This section explores whether science teachers in South Africa view interactive simulations as effective tools for cultivating critical thinking skills in their students.

2.4.1 Simulations Based Learning (SBL) as a learner-centred pedagogy

The advent of the technology boom has ushered in a variety of promising digital tools in the classrooms. Simulations Based Learning (SBL), is considered an example of a learner centred pedagogy capable of eliciting conceptual understanding. A learner-centred pedagogy is defined as “an instructional approach in which students influence the content, activities, materials, and pace of learning” (Collins & O'Brien, 2003: 338). The student is the active participant in their own learning. Perhaps a more insightful definition is by Bremmer (2021) who provides a more comprehensive multi-factorial definition of learner-centred pedagogy as one in which learners are actively involved in learning; learners interact with themselves and the teacher; the planning for learning considers the learners' prior knowledge, skills; learning is flexible and adapted to learners' needs and preferences; learners work by themselves; learners take responsibility for their own learning; learners not only learn content but also develop their lifelong 'learning to learn'; content is meaningful and relevant to learners' real lives; learners develop 21st Century skills such as analysis, critical thinking, creativity and lifelong learning; learners become involve in decision-making in dialogue with peers and the teacher; traditional power distances between teachers and students are reduced; there may not necessarily be 'one right answer'; both teacher and students' opinions are valued; learning is seen as an ongoing process, not just a product and formative assessment is a key part of learning. For this study, a learner centred pedagogy is defined as any instructional method that places the learner at the forefront of the educational experience, prioritising their needs, interests, and active participation in the learning process, the role of the teacher is that of guiding and advising, more like a mentor, while the learner takes full charge of their learning. This study seeks to

establish the views of science teachers as to whether or not, interactive simulations, as a learner centred pedagogy, is efficacious in the development of critical thinking skills.

Interactive simulations are computer-generated dynamic models that present theoretical or simplified models of real-world components, phenomena, or processes (Bell et al., 2008). Thompson, Simonson, and Hargrave (1996) explain simulations as representations or models of an event, object, or some phenomenon. Computer simulations are programs that allow the learners to interact with a computer representation of either a model of the natural or physical world or a theoretical system (Weller, 1996). Due to their versatility, interactive simulations offer a wide range of advantages. The following are some of the notable advantages of interactive simulations.

Interactive Simulations cater to the needs of 'Visual' learners. When a person views something, there is interpretation of the visual stimulus which takes place. Students' visual interpretation can be observed from the knowledge that they construct from the visual. Visuals promote students' ability to organize and process information. Visuals can also be utilized to challenge students to think on levels that require higher order thinking skills (Smith and Blankinship, 2000). They can give real environments structure according to principles in the domain. Spatial, temporal, and causal phenomena can be represented that may be otherwise unobservable and not directly manipulatable because they are too large (hurricanes), or too small (chemical reactions), too fast (earthquakes), or too slow (plant growth) (Quellmalz, 2012).

SBL allows students to engage in real-world situations without the fear of negative consequences (Rico, 2022). This approach not only enhances students' understanding of complex concepts but also provides a platform for them to assess and improve their skills in a safe and supportive setting. When lessons are enriched with simulations, learners can observe patterns and links of concepts in a way similar to experts (Falvo, 2008). Simulations also help students deal with the problem of unfamiliarity with scientific science language (Hanson, 2017). SBL provides learner-centred environments that allow students to explore systems, manipulate variables and test hypotheses (Windschitl, 1998). By combining animations and visualizing science concepts, simulations can support the development of insight into complex phenomena (Akpan, 2001). Simulations can be used in class when equipment is not available, or when it is not practical to set it up (Wieman et al., 2010). Another application of simulations is for doing experiments that would otherwise be impossible to do.

Variables can easily be changed in simulations in response to students' questions, where this is not always possible with real equipment. Students can practice laboratory techniques before engaging in lab experience with real equipment (Akpan, 2001). Actions such starting, stopping, and replaying a simulation can allow focusing on specific parts and actions. A simulation that allows zooming and control of speed are even more likely to be facilitating more deep learning (2004; Stieff, 2011; Ryoo & Linn, 2012). SBL provides immediate feedback Carlos et al. (2023), and this is instrumental in cultivating students' deductive and inductive reasoning skills. By evaluating various theories and perspectives critically, the students can develop the aptitude to recognise assumptions and draw more reasoned conclusions Bonesso et al. (2023). As (Yablon, 2022) puts it, the immediate feedback allows students to assess the effectiveness of their thought processes and decision-making strategies, they can see in real time, how their actions and decisions are affecting the outcome. By immersing students in realistic scenarios, simulations make the learning experience more engaging and memorable. This helps students connect theory to practice and develop a deeper understanding of the subject matter. Active learning strategies are efficacious in fostering critical thinking (Xu, 2023; Yeung., 2023). SBL has been reported to offer meaningful learning by providing scaffolding effects (Laxman and Chin, 2011), scaffolding refers to cases in which the tool changes the task in some way so that learners can accomplish tasks that would otherwise be out of their reach to learn (Reiser, 2004). SBL fosters collaboration and teamwork, which are essential skills in today's interconnected world. Many simulations require students to work together, negotiate, and make collective decisions. This collaborative element exposes students to diverse perspectives and reasoning approaches, broadening their understanding of complex issues and promoting critical thinking (Yablon, 2022). After the simulation activity, students usually participate in a debriefing session where they can reflect on their actions, the decisions they made, and the reasoning behind these decisions. This reflection process is pivotal in developing critical thinking as it enables students to assess the efficacy of their thought processes and decision-making strategies (Woodward et al.2023).

2.4.2 The link between Simulations Based Learning (SBL) and critical thinking skills.

Conceptual understanding is antecedent to the development of critical thinking skills. Interactive simulations in science education have gained increasing attention as tools to enhance critical thinking among students. It is necessary to find the nexus between

the characteristics of critical thinking and the features of interactive simulations. Whitten and Brahmasrene (2011) describe critical thinking as the cognitive engine which drives problem-solving and decision-making. Rousseau (2012) states that critical thinking involves questioning assumptions, evaluating evidence, and testing the logic of ideas, proposals, and courses of action. Watson and Glaser (1980), define critical thinking as a process of analysing, synthesizing, and evaluating information collected through observation, reflection, experience, or communication that may lead to a belief or action. Another definition includes reasonable and reflective thinking, focusing on comparing decision alternatives (Ennis & Millman, 1985). The multiplicity of definitions of critical thinking point to the fact that the concept means different things to different people. The lack of a standardised operational definition can be a serious challenge to the novice. There is, however, common ground as far as the overarching tenets of critical thinking are concerned. Critical Thinking is purposeful, self-regulatory judgement which results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgement is based (Facione, 1990 cited in Zhao, Pandian and Singh 2016). Kuhn (1999) argues that critical thinking belongs to the highest level of mental abstraction which he coins Epistemological Meta-knowing. This level defines critical thinking as a level typified by the propensity to use judgment, evaluation, and argumentation to sift through opinions and arrive at those that are most valid, appreciating that not all opinions should be valued equally but rather that, reason, logic, and empirical evidence can be used to privilege certain positions over others (Kuhn, 1999). Another authority in the domain of cognitive development, Benjamin Bloom, posits that critical thinking refers to the mental processes of analysis, synthesis and evaluation, and is commonly used in activities such as problem solving, reasoning, thinking, assessing and concluding (Bloom, 1956). Bloom went so far as to show that thinking is hierarchical, as illustrated by what is commonly known as Bloom's Taxonomy. Bloom's taxonomy is the underpinning theoretical framework for the measurement of cognitive development in the South African context. According to Mayer, critical thinking involves the development and growth of thoughts, analysis, questioning, and reflecting on realities and experiences and applying them to problem solving (Mayer, 1986).

Research has indicated that providing learning environments that influence student engagement through the use of active learning strategies, may enhance students' retention and application of information and contribute to student success (Dewing, 2010). Active learning enables students to talk and listen, read, write, and reflect as they approach course content through problem-solving exercises, informal small groups, simulations, case studies, role- playing, and other activities, all of which require students to apply what they are learning (Meyers and Jones, 1993). Dewing (2008), states that active learning embeds critical thinking in the learner and encourages life-long learning to ensconce retention of knowledge and skills. There is a substantial body of research which supports the claim that critical thinking skills development is best achieved through experiential learning (Dewey, 1938; Kolb, 1984; Whetten, 2007). Critical thinking therefore can be honed intentionally.

From the afore mentioned characterisations of critical thinking skills, it would appear that interactive simulations as instructional tools are well tailored to hone critical thinking skills. A study in Morocco by Hassouni, Ibrahmi Lamri and Ouahi (2022) explored perceptions of science teachers on the effectiveness of interactive simulations in fostering critical thinking skills. The findings indicated that a majority of teachers acknowledged the positive impact of interactive simulations on students' ability to analyse, evaluate, and apply scientific principles. In contrast, Holmes, Perkins, Price, and Wieman (2018) conducted a study among science educators in the United States of America and found out that some teachers had reservations on the integration of interactive simulations in science. A sub-set expressed concerns about the potential distractions and need for proper guidance to ensure that critical thinking is effectively nurtured. Similarly, a case study conducted in the South African province of the North West, by Sebatana and Dube (2022), established that interactive simulations can potentially result in misconceptions. Learners may get conditioned into thinking that scientific experiments produce precise results and have limited risks. Erdem (2019), conducted classroom observations and interviews, and reported significant improvement in critical thinking abilities as a result of the increased student engagement and self-paced learning. In a study using the University of Colorado Physics Education Technology PhET simulations, conducted by Hannel and Cuevas (2018) in Atlanta, Georgia, the findings seemed to support a positive shift in critical thinking dispositions of learners. The teachers reported that the use of interactive simulations helped to develop skills just as well as using real lab equipment.

The multi-media nature of the simulations was credited with stimulating deep learning across all learning styles. Dieker, Howell, Hynes and Mikeska (2023) conducted research study among science and maths teachers in United States of America. Their research findings indicated both commonalities and variations in teachers' perspectives regarding the use of interactive simulations to foster critical thinking skills. The study emphasised the need for culturally responsive approaches in integrating such tools. In order to gain more insights into the views of science teachers regarding such an important pedagogy that is sensitive and responsive to the various learning styles, and has the ability to mediate conceptual understanding, this study seeks to establish whether or not science teachers in South Africa perceive interactive simulations as tools with the efficacy to develop critical thinking skills in their learners.

2.5 Methods used by science teachers to assess critical thinking skills

There are many ways critical thinking skills can be assessed depending on the context. Science teachers can use validated and reliable instruments to assess critical thinking skills based on a student's performance on a given task (Bissell and Lemons, 2006). There are various critical thinking tests such as: The California Critical Thinking Skills Test (CCTST), Watson-Glaser Critical Thinking Appraisal (WGCTA), and Halpern's Critical Thinking Assessment (HCTA). The aspects of critical thinking measured by these tests include cognitive skills such as analysis, evaluation of argument, and synthesis. Critical thinking within a subject-domain such as science enables a person to think, evaluate, and solve problems in scientific ways (Santos, 2017), therefore suitable assessments focus on students' understanding of the content together with the relevant skills to maximise the learning outcome.

Aspects of laboratory reports can be used to assess critical thinking skills. To investigate whether students can do real scientific research thinking and writing, the teacher focuses on the student's ability to building investigative questions, hypothesis-building, analysis of results, cogent justifications and explanations of results and drawing appropriate conclusions (McDonald, 2012; Katchevich, Hofstein & Mamlok-Naaman, 2013). Grading rubrics can be used to assess critical thinking skills by focusing on the students' ability to identify the claim being made and the validity of evidence in science articles from the press or science journals (Terry, 2012). Teacher observation is another method that can be used to assess critical thinking skills of students. Using articles from textbooks or other media, the teacher can assess the

students' analysis and evaluation of the article using scientific perspectives (Belova and Eilks, 2015). Interviews or questionnaires can also be used to assess critical thinking skills (Abubakar and Arshad, 2015; Yu, Lin & Chang, 2017). The teacher focuses on students' ability to recognise assumptions, their ability use inductive and deduction reasoning, interpretation of facts and evaluation of the students' arguments. The teacher needs to target specific skills for assessment and construct the relevant tasks and instruments to measure the skills. This study seeks to find out what methods science teachers in South African schools use to assess critical thinking skills.

2.6 What schools can do to help science teachers use interactive simulations to foster critical thinking skills.

The task of integrating technology into classroom instruction in a meaningful and state-of-the-art way remains challenging (Pittman & Gaines, 2015). Several researches find that teachers have difficulties in integrating technology into their lessons (Erdem, 2019; Proctor, Finger, Cavanagh, and Fitzgerald, 2013), due to current lack of materials in schools, lack of consultant staff to guide teachers, insufficient professional development in the field of technology, complaints about time pressure due to teachers' inability to manage time effectively and teachers' lack of competence in information technology, and pressing concern about whether the use of interactive simulation can directly contribute to test scores (Bo, Fulmer, Lee, and Chen, 2018). According to Byrom and Bingham (2001), effective use of interactive simulations in classrooms starts with the school leadership. The school leadership must have a clearly articulated vision on the integration of technology in teaching. School leadership with the inclination to use technology inspire teachers to do the same. School principals must have a clear idea about how technology can support best practices in instruction and assessment, they use technology fluently; and they must actively seek professional development opportunities. Build the 21st Century Classroom (2018) emphasise that schools should prepare the classrooms for technological advances by paying particular attention to the infrastructural and networking needs of the school. Provision of suitable devices and strong wi-fi signal should be a priority for connectivity (Pearson, 2015). Even with adequate technology access, effective professional development remains a reason that makes it difficult to increase the level of technology integration in classrooms. Little is understood about what these experiences might look like for teachers on the ground, during implementation of

technology-integrated professional development (Wilkerson, Andrews, Shaban, Laina, and Gravel, 2016). Research shows that simply providing teachers with professional development opportunities related to using technology does not necessarily translate into higher levels of integration in the classroom. Schools must provide teachers with the knowledge, skills, resources, and support in order for them to integrate technology in the curriculum and to maximise its effects on teaching and learning (Papanastasiou, Zemblyas, and Vrasidas, 2003). Most teachers need training on how to integrate technology in content specific teaching areas like science (Rotermund, De Rocje, and Ottem, 2017). Policy on the use of technology should therefore not be generic. Research shows that there is a significant correlation between teacher's use of technology in the classroom with their self-efficacy (Li, Worch, Zhou, & Aguiton, 2015). According to the theory of self-efficacy, an individual processes, weighs, and integrates diverse sources of information concerning their capability, and they regulate their choice behaviour and effort expenditure according to that information (Bandura, 1977). As teachers try new strategies and adopt new technologies, they are bound to stumble; it is up to the principal to assure them that it is okay to be less than graceful as they are learning. The school leadership must highlight and commend the efforts of teachers who attempt to use technology to improve teaching and learning. This will motivate teachers to continue doing so and encourage other to start using technology in their classrooms.

The school could pay and arrange time off for science teachers to attend workshops convened by specialists in the area of educational technology. There are also subject specific conferences that the school can facilitate the science teacher to attend. The school could invite experts for whole school improvement programmes on integration of simulation-based learning where science teachers could benefit. The teaching timetable of science teachers could be made flexible such that they can avail themselves for mentorship on the use of simulations in science, either by fellow science teachers in their locality or by information technology teachers. One of the positive effects of mentoring as found in a study by Gjedia and Gardinier (2018) is that it helps to build a professional identity. Muršak, Javrh, and Kalin (2011:72) noted that "an important part of a professional identity is the image of an ideal teacher. This ideal is the abstraction of concrete persons and their properties". Just like children's characters can be modelled by the people around them, so to can the ideal professional character be

influenced by mentors. Schools could encourage science teachers to enrol for short courses on educational technology offered by colleges or universities.

The school can take a more proactive role in mitigating the lapses in integration of technology such as interactive simulations in science instruction by actively encouraging their teachers to embrace technology and by offering various professional development opportunities. This study seeks to establish what help the science teachers in South African schools feel the school can provide to enhance their use of interactive simulations to foster critical thinking skills.

2.7 Summary of chapter 2

This chapter laid the groundwork for investigating the potential of interactive simulations in fostering critical thinking skills within science education. A review of the literature revealed the **TPACK framework** as a key theoretical foundation. This framework, established in the literature, highlights the importance of considering content knowledge, pedagogical knowledge, and technological knowledge for successful technology integration in the classroom. Recognising the influence of teacher perceptions on technology adoption, the chapter explored various factors impacting educators' decisions. Models such as the Theory of Planned Behaviour provided insights into these factors, such as attitudes, social norms, and perceived behavioural control. Understanding these factors is crucial when investigating teacher perceptions of interactive simulations, as identified in the reviewed literature.

The chapter then examined Simulations-Based Learning (SBL) as a promising pedagogical approach for fostering critical thinking skills. The literature suggests that SBL's inherent flexibility and emphasis on active learning create an environment conducive to developing critical thinking.

CHAPTER 3 RESEARCH METHODOLOGY

3.1 Introduction

This chapter outlines the research methodological approach adopted for this research. Research methodology has many components which include the philosophical theory underpinning the research, what type of data to collect, qualitative or quantitative; the research design or overall strategy; sampling methods or who to collect the data from; data collection procedures; ethical considerations including the choice and design of the instruments used in data collection and analysis. The methodology sheds light on the necessary steps taken by the researcher to ensure the validity of the research findings. This chapter will therefore give consideration to each of the components above in detail.

3.2 Research Design

This section examines the research design employed in this study. Section 3.2 begins by outlining the study's paradigm, specifically focusing on the Constructivist (Interpretivist) approach. This paradigm emphasizes the socially constructed nature of reality and the importance of participant interaction in knowledge creation. Following this, the section details the study's ontology (nature of reality) as relativist, acknowledging the multiple realities of science teachers' perceptions. The epistemology, which is the theory of knowledge, is then identified as subjectivist, highlighting the researcher's role in meaning-making through data analysis. Finally, the section addresses the axiology, or values of the study, ensuring informed consent and participant anonymity.

3.2.1 Paradigm of the study

This study will be situated in the Constructivist (Interpretivist) paradigm. The main tenet of this paradigm is that reality is socially constructed (Bogdan & Biklen, 1998). By interacting with fellow educators and gaining insights into their practices and perceptions, the researcher will be in a position to create new knowledge. Furthermore, the constructivist paradigm stresses that one should not only collect information but also connect such information with their previous knowledge to enable them to develop a better understanding of the process (Huang, Rauch & Liaw, 2010). Vygotsky (1978) posits that creating new knowledge depends on an individual's ability to interact socially with others, implying that communication is an essential component of learning and it can only be done in collaboration with others. The collaboration can be directly

between a group peers or with the assistance of written responses which the researcher can analyse and distil in an effort to create new knowledge.

3.2.1.1 Ontology of the paradigm of the study

Ontology is the philosophical study of the nature of existence or reality, of being or becoming, as well as the basic categories of things that exist and their relations (Scotland, 2012). This study seeks to establish the perceptions of science teachers on the use of interactive simulations to foster critical thinking skills. Naturally, there are factors that will contribute to each science teacher's views based on their context. This study was therefore based on the relativist ontology. This is because the researcher believed that the subject of the study had multiple realities, and that those realities could be explored and meanings made of them or reconstructed through human interactions between the researcher and the subjects of the research, and among the research participants themselves.

3.2.1.2 Epistemology of the paradigm of the study

By focusing on narratives, stories, perceptions and interpretations of the science teachers in the study, and then creating new knowledge to contribute to world views, this study lends itself to a **subjectivist epistemology**. The researcher makes meaning of their data through their own thinking and cognitive processing of data informed by their engagements with participants (Punch, 2005). In order to collect data for the study, the researcher and the subjects will engage in interactive processes in which they intermingle, dialogue, question, listen, read, write and record research data. While the researcher will apply the relevant tools in the analysis of data, every effort will be made to remain objective and thus avoid any biases.

3.2.1.3 Axiology of the paradigm of the study

The participants will sign consent forms to the effect that they are voluntarily participating in the research and that none of their personal details will be shared with third parties without their express authority(see **appendix 5**).

3.2.2 The Research Approach

This qualitative research adopted a naturalistic approach towards the research subjects, because the research focus was on the lived experiences of the people and their world (Denzin and Lincoln, 2005). Armour and Macdonald (2012) aver that all qualitative research has common threads by way of key characteristics. The researcher is the main tool for data collection and analysis. Secondly, the researcher actively engages in the

field work whereupon he or she interacts with subjects of the inquiry in their natural setting in order to collect data using appropriate relevant tools. Furthermore, qualitative research relies on inductive research strategies, where the research aims to build abstractions, concepts, or theories. Language is used to characterise the findings. It is noteworthy that a qualitative approach is prone to subjectivity issues by virtue of the researcher being the primary tool for collection the data (Armour and Macdonald, 2012).

On the other hand, quantitative research attempts to gather data by objective methods in order to provide information about relations, comparison and predictions, without the subjectivity of the one carrying out the inquiry (Armour and Macdonald, 2012). According to (Weber, 2004), reality and the researcher are two distinct things that do not interact with each other during the data collection process, unlike the case of qualitative research. The researchers are able to control the variables or environment so that they able to link the cause and effect. A fusion of qualitative and quantitative research is deemed to be a mixed approach.

This study followed a qualitative approach with a **naturalist methodology** in which the researcher used data gathered through interviews, surveys and reflective sessions, with the researcher acting as a participant observer. The overarching aim of qualitative research is to understand complex psycho-social issues hence it is best at addressing the “why” and “how” questions in the inductive process of organising data into categories/themes and patterns (Creswell, 2013).

3.2.3 Research strategy

To gain insights into the perceptions of science teachers on the use of interactive simulations to foster critical thinking, a phenomenological study was conducted. A phenomenological study examines the lived experiences of research subjects, ranging from perception, thought, memory, imagination and social activity, including linguistic activity (Smith, 2016). People differ in how they experience a given phenomenon in their world and that these differences can be described and communicated by them and understood by others (Edwards, 2006; Marton and Booth. 1997). It is the collective experience of the phenomenon that is the focus, not the individual participants' experiences (Creswell, 2013).

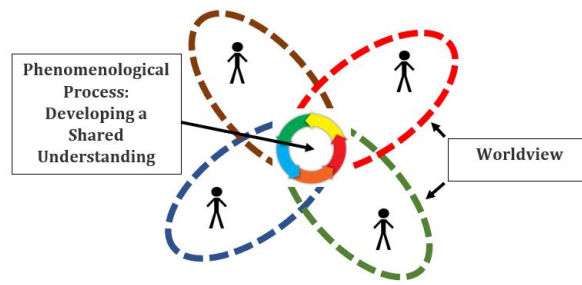


Fig 3.1 Phenomenology. <https://uta.pressbooks.pub/advancedresearchmethodsinsw/>

This study was interested in how teachers make sense of interactive simulations and their role in fostering critical thinking skills. Phenomenology allowed the researcher to explore the individual and collective meanings participants construct around this phenomenon, considering their perceptions, thoughts, and memories. While individual experiences are valuable, phenomenology aims to capture the essence of the shared experiences, collective consciousness of science teachers regarding the use of interactive simulations to foster critical thinking skills. This aligned with the study's goal of understanding teachers' overall perceptions of this technology, not just isolated viewpoints.

3.3 Population and sample.

The participants were drawn from seven Independent schools of the ieb Bedfordview Cluster of Johannesburg.

3.3.1 The participants

In this study, eight Physical Science teachers from seven South African Independent schools in the Bedfordview Cluster of Johannesburg constituted the participants. The researcher's school was a member of the chosen cluster. The schools were within a reasonable radius of each other and therefore easily accessible. The participants were well acquainted with the researcher and had held professional development together before. Much of the study was conducted at cluster meetings where the educators met as a collective, thus saving on time and transportation costs.

3.4 Data Collection

According to Cohen and Manion (2011), data collection is the process of gathering data from research sites, people or documents. In empirical research this is an

indispensable process and very crucial stage without which it would not be possible to get the results of the study.

3.4.1 Research Instruments.

To comprehensively assess science teachers' perceptions of interactive simulations for critical thinking development, this study employed a combination of surveys and questionnaires. These instruments provided a standardized approach to data collection, allowing for efficient gathering of information from multiple participants. Furthermore, the chosen surveys and questionnaires were established and validated in prior research on science education and technology integration. This established validity and reliability ensured the instruments effectively captured the teachers' perceptions with a high degree of accuracy and consistency even though minimal adaptation was needed to align with use of interactive simulations to foster critical thinking skills.

3.4.2 Data gathering techniques

Data collecting techniques are the ways and means by which data is collected (Boudah, 2011). In this study, data gathering was done by means of a survey and semi-structured interviews with selected eight Physical Science teachers at seven Independent schools that constitute the Bedfordview Cluster. In answering the open-ended questions the participants could express themselves freely. The researcher had the opportunity to probe to elicit more information.

3.4.3 Data gathering Procedure

In this study the data gathering steps included identifying the Physical Science teachers who took part in the study, getting their informed consent, getting ethical clearance and then setting up appointments to carry out the semi-structured interviews with the participants. The surveys were sent to the eight participants who later participated in the interviews. The semi-structured interviews took a one-to-one mode with the eight participants. The responses were captured by use of an electronic device in the form of a cell phone and then subsequently transferred to a lap top and an external computer hard drive.

3.4.4 Data Management

In order to secure the data collected in this study, the data was kept on multiple devices, namely a laptop and an external hard drive. The data on electronic devices was then transcribed once the interviews were done.

3.5 Data Analysis

According to Denzin and Lincoln (2017) data analysis is the interpretation of the data collected. Creswell (2009) says in qualitative research there are three broad categories of data analysis, that is, analytical analysis, grounded theory and narrative analysis. Thematic analysis which is a sub-category of narrative analysis was used in this study. Thematic analysis involves the identification of common themes or codes which emerge from the data gathered. This was followed by an analysis of the relationships between codes and typologies with attributes. The constructs of TPACK were used to identify the themes emerging from the interview responses.

3.6 Reflexivity

It is natural that the researcher will have opinions and a relationship with the subject of inquiry. As the main tool of data collection, it is difficult for researchers to completely insulate themselves from what they research. This gives rise to the phenomenon of reflexivity which, according to Hess-Buber (2007: 17), refers to how researchers reflect on, appreciate and understand the extent to which their "...social background, location and assumptions affect their research practice." In this study, being a fellow Physical Science teacher in the same environment as the subjects of research, that creates a potential measure of bias in the way in which the researcher interprets the data gathered. To mitigate this potential weakness, interpretation of results will be based on what scholarly literature says. on academic leadership, in general and, middle level academic leadership, in particular says.

3.7 Verification of Qualitative results

In this study, the credibility of data was achieved through a triangulation of the responses from the survey and the interview data which was gathered. The data gathered could potentially apply to all the Physical Science teachers in similar settings. The results were therefore transferrable to other schools in South Africa and beyond.

In this study, the audio copies of the interviews as well as the transcriptions thereafter were used to ensure that all the views expressed in the interviews are correctly captured.

3.8 Ethical considerations

Informed consent means all participants were fully informed of what the research was all about and what was required of them, how the data would be stored and used as well as who would have access to that data. The participants in this research were provided with an informed consent form and were required to provide explicit, active, signed consent to take part in the research, this included a clear statement to the effect that they had understanding of their rights to access the information they contributed and the right to withdraw at any point without any negative consequences to them. It was important for the identity of participants to be kept confidential or anonymous. The identity of the participants in this research was protected through codification or data pseudonymisation using random names with no bearing whatsoever to the actual identities of the respondents. This protection was aided by avoiding the use of self-identifying statements such as “we at Buse, do...”. Potential for harm refers to all possibilities of psychological, social, physical or legal harm that might be visited upon the participant by virtue of their involvement in the research study. These potential fall outs were candidly discussed with respondents to alert them of their existence while allaying their fears that all possible measures were in place to safeguard them against any such harm. No sensitive questions such as may trigger negative emotions that might result in psychological harm were asked. Through pseudonymisation, all the respondents’ data could not be linked them. This mitigated the risk of public embarrassment or stigma. Short of a hoarse voice or falling from a chair during the interview session, there were no perceived physical risks attributable to this study. To avoid the potential of legal risks, no sensitive questions were asked. The data was stored on the researcher’ portable hard drives and protected with a unique password. Once transcribed, the responses were shared with the respondents to verify that their responses were captured correctly.

3.9 Presentation of findings

The findings of this study were presented in a clear and organized manner. Data was displayed in tables, utilising well-defined codes to represent identified themes. To further illustrate the perspectives of the science teachers, some of their verbatim

responses were directly quoted, providing a powerful voice to their experiences and perceptions.

3.10 Summary of chapter 3

This chapter focused on the methodology of the research project. The research philosophy of the study in the interpretivist/ constructivist approach whose overarching tenet is that reality is constructed based on social interactions. The research approach adopted is the inductive interpretive phenomenological qualitative approach. The research strategy will be the one on one interview with respondents although this will be preceded by a survey to align the credentials of the subjects with the research goals. Purposive convenience sampling will be used, followed by thematic analysis of the data. Data gathering techniques and procedures were also discussed. Interview sessions will be scheduled with participants and semi-structured questions will be used. The data collection instruments are adaptations of two published scholarly works to ensure their validity. Data management was also brought into focus. The responses will be recorded both electronically and on paper. The audio recordings will then be transcribed and shared with the respondents to ensure credibility of results. Analysis of the results will be done using themes and codes that will emerge from the Technological Pedagogical and Content Knowledge (TPACK) framework, which is the conceptual framework underpinning this study. The chapter also outlined appropriate measures to ensure validity and reliability of findings. Ethical considerations were also clearly outlined. Chapter 4 presents the insights gleaned from the data analysis. Thematic analysis was employed to identify recurring themes within the teachers' interview responses. These themes were then meticulously analysed and discussed in relation to the TPACK framework. This analysis provided a deeper understanding of the interplay between content knowledge, pedagogical knowledge, and technological knowledge that shaped teachers' perceptions of interactive simulations for critical thinking development. Furthermore, the chapter engaged in a critical discussion of the findings, exploring their implications for science education practice and future research directions. The methodology outlined in this chapter informed the analysis and discussion in chapter 4.

CHAPTER 4 RESULTS PRESENTATION, ANALYSIS AND DISCUSSION

4.1 Introduction

Chapter 4 covers the presentation, analysis and discussion of the findings thereby creating meaning of the insights gleaned from the interviews with science teachers. The chapter begins by introducing the science teachers who participated in the study, ensuring their anonymity through the use of pseudonyms. The focus then shifts to the thematic analysis of the interview data. This analysis identified recurring themes and codes that emerged from the teachers' responses, providing a deeper understanding of the factors influencing their use of interactive simulations. Themes explored aspects like the teachers' own knowledge and comfort level with technology, the level of support they received from their schools, and how they considered their students' needs when incorporating simulations. The thematic analysis of the teachers' perceptions of interactive simulations then followed. The analysis examined how the teachers viewed this technology's potential for fostering critical thinking skills in their students. Additionally, it explored how teachers perceived the impact of simulations on student engagement and motivation in the classroom. Furthermore, the thematic analysis investigated how teachers viewed the integration of simulations within the existing science curriculum. The chapter also explored concerns teachers raised regarding the use of simulations, identified through thematic analysis. This included concerns about potential biases within the technology itself and the technical hurdles associated with implementation. Teachers' openness to the use of interactive simulations ranged from enthusiastic adoption to a more sceptical viewpoint. Finally, Chapter 4 examined the methods currently used by science teachers to assess critical thinking skills. This section explored the strengths and limitations of these existing methods and discussed how they might be improved, potentially through the use of interactive simulations, to provide a more comprehensive picture of student learning. The respondents to this study were referred to as Kabudura, Dzasukwa, Mushamba, Bonzo, Hardlife, Mandireva, Chenzira and Jekunareta.

4.2 Biographical data of respondents

Table 4.1: Biographical data

Attribute	Number of teachers	%
Age:		
30 – 39 years	1	12.5
40 – 49 years	5	62.5
50 – 60 years	2	25
Gender		
Male	3	37.5
Female	5	62.5
Qualifications		
Bed	4	50
BEd (Hons)	1	12.5
BSc	2	25
Med	1	2.5
Teaching Experience		
Less than 5 years	1	12.5
5 to 10 years	2	25
More than 10 years	5	62.5
Levels Taught		
GET (GR 7 -9)	2	25
FET (GR 10 -12)	6	75

The biographical data of respondents was included to show the diversity of the sample in terms of age, gender, qualifications and experience. The age range, qualifications and experience spoke to the expertise of the teachers. The teachers were suitably qualified and had significant experience to warrant the ability to employ different strategies such as interactive simulations to foster critical thinking. Grades taught added a layer to the diversity of perspectives in terms of the adaptability of interactive simulations to foster critical thinking skills.

4.3 Factors that influence the use of interactive simulations by science teachers.

Table 4.2 Factors influencing science teachers' use of interactive simulations

Category	Factor	Description of TPACK factor as used in this study
Teacher-Related Factors	Technological Knowledge (TK)	Understanding of simulation technology, functionality, and integration with existing systems.
	Pedagogical Knowledge (PK)	Ability to design engaging lessons incorporating simulations, scaffold learning, and differentiate instruction.
	Content Knowledge (CK)	Understanding of scientific concepts targeted by simulations and their connection to real-world applications.
	Technological Pedagogical Knowledge (TPK)	Ability to harness simulations to enhance pedagogical strategies and promote deeper learning.
	Pedagogical Content Knowledge (PCK)	Adapting simulations to specific scientific concepts and student learning levels for effective knowledge construction.
	Technological Content Knowledge (TCK)	Understanding how simulation features and limitations align with scientific content and learning objectives.
	Attitudes and Beliefs	Openness to technology, comfort level with learning new tools, and perceived value of simulations for science education.
Contextual Factors	Time Management and Planning Skills	Integrating simulations effectively within lesson plans and managing classroom time effectively.
	School Administration and Leadership Support	Access to funding, professional development opportunities, and technical support for simulations.
	Technology Infrastructure and Resources	Availability of adequate hardware, software, internet connectivity, and technical support personnel.
	Student Characteristics and Needs	Diversity of student learning styles, access to technology at home, and prior experience with simulations.
	Curriculum and Assessment Practices	Alignment of simulations with curriculum standards and assessment expectations.
	Classroom Culture and Learning Environment	Student engagement, collaborative learning opportunities, and classroom rules that support technology use.

Table 4.2 above is a summary of the classification of factors and their descriptions as applied in this analysis. Analysis of the teachers' responses to the sub-research question: What are the factors that influence the use of interactive simulations by science teachers?, revealed a complex interplay between various factors and science teachers' decisions regarding their choice to use or not to use interactive simulations. The factors were initially classified as 'Teacher related' or 'Contextual'. The factors were then further decomposed into themes and codes for discussion. The teacher related factors delved into the individual teacher's self-efficacy with regard to the TPACK framework. The teachers were asked to rate themselves on a scale from 1 to 5 against each TPACK dimension, where 1 was the lowest level and 5 as the highest. The graph below represents the data.

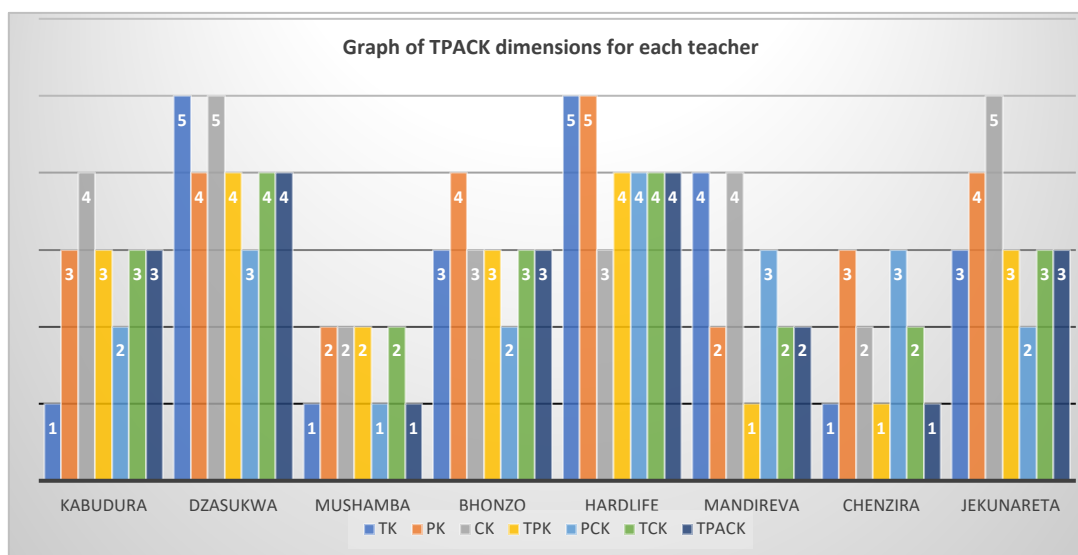


Fig 4: 1 TPACK dimensions for the participants.

Table 4.3 Themes - Factors that influence use of interactive simulations by science teachers

Theme - factor	Code	Positive Influence on Simulation Use	Negative Influence on Simulation Use
Teacher Knowledge and Skills	TK	Strong understanding of technology and integration options	Limited access to technology, lack of training
	PK	Skilled in designing engaging and differentiated lessons	Preference for traditional methods, limited understanding of how to integrate simulations
	CK	Deep understanding of science concepts and real-world connections	Concerns about curriculum alignment, difficulty finding relevant simulations
	TPK	Ability to use simulations to enhance teaching strategies	Lack of experience or confidence in using simulations effectively
	PCK	Skilled in adapting simulations to specific content and student needs	Lack of understanding of how to adapt simulations, difficulty tailoring to diverse learners
School and Infrastructure Support	TCK	Understanding of how simulation features align with content and learning objectives	Limited knowledge of simulation features and limitations, inability to identify suitable simulations
	School Administration and Leadership Support	Strong support for professional development, funding, and technical resources	Inadequate funding, limited professional development opportunities, lack of administrative support
Student Factors	Technology Infrastructure and Resources	Reliable technology infrastructure with adequate hardware, software, and internet access	Insufficient hardware, software, or internet connectivity, lack of technical support personnel
	Student Characteristics and Needs	Diverse learning styles, strong technology access at home, prior experience with simulations	Limited technology access, specific learning needs not well-supported by existing simulations
Teacher skills, Beliefs and Attitudes:	Attitudes and Beliefs	Openness to technology, positive beliefs about simulations' value in science education	Negative attitudes towards technology, scepticism about simulations' effectiveness
	Time Management and Planning Skills	Strong planning and time management skills for integrating simulations	Limited time for planning and lesson preparation, challenges managing classroom time with simulations
	Curriculum and Assessment Practices	Curriculum aligned with available simulations, assessments compatible with simulation-based learning	Misalignment between curriculum and existing simulations, assessment practices incompatible with simulations
	Classroom Culture and Learning Environment	Collaborative and supportive environment that encourages technology use	Traditional classroom culture with limited technology integration, lack of support for student collaboration

Scrutiny of the influencing factors revealed four basic themes: Teacher Knowledge and Skills, School and Infrastructure Support, Student Factors, and Additional Factors. The themes had both positive and negative components. Table 4.3 below gives a summary of the themes and their respective codes.

4.3.1 Teacher Knowledge And Skills

The integration of interactive simulations into science classrooms holds immense potential for enhancing student engagement and understanding of complex concepts. However, research reveals that not all science teachers embrace this technology with equal enthusiasm. Their use of simulations varies widely, prompting the intriguing question: **what factors influence the adoption and utilisation of interactive simulations by science teachers?** To answer this, there is need to delve into the intricate interplay between teacher knowledge and skills. The research explored how their understanding of simulations, pedagogical expertise, comfort with technology, and access to resources all shape their decisions about employing these powerful tools in their classrooms. Unravelling the intricacies of this interplay will not only provide valuable insights into teachers' current practices but also guide the development of targeted support mechanisms that empower them to unlock the full potential of interactive simulations for effective science education.

Based on the data in Fig 4.1, this study established that the use of interactive simulations by science teachers hinges on a complex interplay of teacher knowledge and skills (TPACK). Factors like strong technological knowledge, pedagogical expertise, deep content understanding, and the ability to blend them to enhance teaching strategies (TPK) were repeatedly cited as a positive influence on the use of interactive simulations. On the other hand, limited technology access, traditional teaching preferences, curriculum alignment concerns, lack of experience with effective integration (TPK), difficulty tailoring to diverse learners (PCK), and limited understanding of simulation features were roundly identified as negative influences. Regarding curriculum alignment, this was what some of the respondents had to say in response to the question: How well do interactive simulations align with the existing science curriculum, and to what extent do you feel that these simulations support the curriculum?

Kabudura:

"Simulations, when chosen well, can be powerful curriculum complements! They can visualize complex phenomena, engage students in inquiry-based learning, and provide immediate feedback. I use them to introduce challenging concepts, build curiosity, and then bridge the gap with real-world investigations. It's not a replacement, but a dynamic tool that can bring the curriculum to life."

Kabudura's statement provided a compelling argument for the use of well-chosen interactive simulations in science education. He highlighted several key advantages. Firstly, simulations can break down complex scientific concepts into more manageable and visually appealing components, making them easier to grasp than traditional textbook learning, especially for abstract concepts. Secondly, interactive simulations encourage students to actively explore and experiment within a safe digital environment, fostering critical thinking skills and promoting a "learning by doing" approach. Many simulations also provide immediate feedback, allowing students to identify areas of understanding and areas that require further exploration. This feature promotes self-directed learning. Furthermore, simulations can be used to introduce challenging concepts in a way that piques student curiosity and motivates them to learn more, creating a foundation for deeper exploration through real-world investigations. Finally, simulations can serve as a bridge between theoretical knowledge gained in the classroom and practical applications in the real world. Interestingly, a strong majority (80%) of the teachers interviewed concurred with Kabudura's perspective, highlighting the potential of interactive simulations to enhance student learning and engagement with complex scientific concepts.

Jekunareta:

"Well, not perfectly. Some simulations cover specific topics well, but often they skip crucial details or go beyond the scope of what needs to be learned. I prefer traditional labs and activities that directly mirror the curriculum objectives. Simulations can be flashy distractions if they don't match what we need to teach."

Jekunareta's comment offered a nuanced perspective on interactive simulations in science education. While acknowledging that some simulations excelled at explaining specific topics, she expressed concerns about a potential lack of depth or a mismatch with the curriculum that had been established. Jekunareta emphasised a preference for traditional labs and activities that directly aligned with learning objectives. This suggested a comfort level with established methods and a wariness of simulations potentially becoming flashy diversions from core concepts that had been taught.

These reservations highlighted the importance of thoughtful integration of simulations into the curriculum. Ensuring simulations aligned with learning objectives and curriculum content had been crucial. Jekunareta's point about some simulations skipping crucial details suggested a need for careful selection, prioritizing those that offered an appropriate level of detail for the intended learning outcome. Furthermore, simulations should have been viewed as complementary tools, not replacements, for traditional labs and activities. By integrating simulations strategically to reinforce classroom learning, educators could address concerns about them becoming distractions. Jekunareta's perspective sounded a warning that while simulations held promise, careful planning and implementation were essential to maximize their effectiveness in the science classroom.

Chenzira:

"Alignment needs work, but it's not a deal breaker. I find most simulations are flexible enough to be adapted. I tweak parameters, design pre- and post-simulation tasks, and link them to specific learning objectives. It takes effort, but I find simulations enhance understanding of abstract concepts, especially if they connect to real-world applications."

Chenzira saw a challenge in aligning simulations perfectly with the curriculum, but she didn't consider it an insurmountable obstacle. Most simulations, in Chenzira's experience, were adaptable. She adjusted settings, created activities before and after using the simulation, and tied everything to specific learning goals. It required extra effort, but Chenzira felt simulations were great for helping students grasp abstract ideas, especially when connected to real-world situations.

Bhonzo:

"Honestly, I haven't seen simulations support the curriculum much. They often lack depth for serious science learning, focus on entertainment over rigour, and for me they can't replace the hands-on experience of a real lab. I stick to tried-and-tested methods like demonstrations and student experiments. Simulations feel like bells and whistles with limited educational value."

The study revealed that not all teachers were convinced about the efficacy of interactive simulations. Bhonzo, for example, was worried that simulations might be too simplistic for serious science learning, focusing on fun over scientific accuracy. Bhonzo believed nothing could replace the value of students getting their hands dirty in real lab experiments. He viewed simulations as flashy extras that didn't contribute much to real learning. Bhonzo's perspective highlighted the importance of choosing simulations carefully to ensure they provide enough depth for the topic. Additionally, activities designed around simulations should focus on analysis and critical thinking, not just entertainment. Simulations should be seen as tools to complement lab experiences, not replace them altogether. By showcasing how simulations can enhance learning, educators can address concerns like those raised by Bhonzo.

The interviews revealed the complexity of integrating interactive simulations into science education. While some teachers, like Kabudura, saw them as powerful complements, others, like Jekunareta and Bhonzo, raised concerns about alignment with the curriculum, depth of content, and potential for distraction. Ultimately, the value of simulations seemed to depend on matching them to specific learning objectives, tailoring their use within lessons, and recognizing their limitations. This positioned them as valuable tools, not replacements, for effective science teaching. In essence, the teachers' own knowledge and skill levels, particularly in technology, pedagogy, content knowledge, and the integration of these areas (TPACK), heavily influenced whether and how effectively they utilized interactive simulations in their classrooms.

The above findings are in agreement with those of Angeli and Voogt (2014) who assert that science teachers' successful integration of simulations is dependent on the interplay of their technology, pedagogy, and content knowledge, or TPACK self-efficacy.

Teachers need knowledge of technology and learner-centred design to personalise learning with simulations (Hew & Brush, 2007; An and Reigeluth,2011; Zhao,2003)

4.3.2 School and Infrastructure Support

The modern classroom pulsates with the hum of technology, promising a revolution in how we learn and teach. Yet, this transformation can only truly flourish amidst fertile ground – a school environment teeming with robust support systems. From dedicated leadership and administration to a dependable technology infrastructure brimming with resources, these pillars provide the essential scaffolding for educators to embrace and excel with educational technology.

However, not all schools bask in this nurturing climate. Some face arid landscapes littered with challenges: inadequate funding, scarce professional development opportunities, and wavering administrative support. These hurdles cast long shadows, stifling the potential of technology to blossom. Similarly, classrooms starved of reliable internet access, outdated hardware, and limited software options struggle to cultivate vibrant learning experiences. This was established from the interviews as indicated in the quotes below.

The theme, School and Infrastructure Support tackles the crucial factors influencing how the science teachers utilise interactive simulations in their classrooms. Two vital domains emerged: School Administration and Leadership Support, and Technology Infrastructure and Resources. As far as School Administration and Leadership Support is concerned, Dzasukwa, Hardlife and Jekunareta reported strong support. Their schools prioritised professional development on implementing simulations, provided adequate funding for acquiring necessary resources, and express leadership buy-in through active encouragement, the science teachers reported a stronger inclination toward embracing and effectively utilising interactive simulations. On the hand, Mandireva and Chenzira reported what they considered to be inadequate support. They lamented limited professional development opportunities, insufficient funding for hardware or software, and lack of administrative endorsement was cited as one of the significant barriers for teachers, hindering their ability to integrate simulations into their teaching repertoire. The second dimension, Technology Infrastructure and Resources, also had two strands, reliable infrastructure, and insufficient

resources. Robust internet access, a stable network, and access to adequate hardware and software specifically chosen for their scientific relevance and ease of use were reported as empowering teachers to seamlessly incorporate simulations into lessons. This information was conveyed through both the survey and the interview as established through triangulation of the data collected using the two instruments. On the other hand, insufficient resources, such as outdated hardware, unreliable internet connectivity, limited software options, and lack of readily available technical support personnel posed formidable challenges, making it difficult for teachers to overcome logistical hurdles and leverage the full potential of simulations. Kabudura, and Mushamba had limited or variable access to technology expressed frustration and no appetite to use interactive simulations. Responding to the interview question: To what extent do you have access to the technological resources such as computers, tablets, or interactive boards, wi-fi connectivity, to effectively integrate simulations into your lessons?, the teachers with good access responded favourably:

Mandireva:

"Resources? We're swimming in them! Every student has a tablet, our lab boasts VR headsets, and the interactive whiteboard makes simulations come alive. The Wi-Fi is a bit iffy at times, but we mostly manage! The challenge is choosing which amazing simulation best fits the lesson."

Mandireva had access to a wealth of technology, with tablets for every student, Virtual Reality headsets in the lab, and an interactive whiteboard. While the Wi-Fi was not perfect, Mandireva's main challenge was choosing the most fitting simulation for each lesson. This abundance of resources allowed Mandireva to fully integrate simulations into her teaching.

Hardlife's response was along the same vein when she retorted:

"We share computers, but the Wi-Fi's decent. So, I adapt! Learners take turns exploring simulations in small groups, discuss findings as a class, and even build cardboard prototypes based on what they learn. It's not ideal, but it sparks their curiosity."

Hardlife's school had a shared computer setup, but decent Wi-Fi. To compensate for the limited computers, Hardlife had students explore simulations in small groups, then discuss their findings as a class. Students even built models based on their learning. While not ideal, Hardlife's approach used the available technology to spark student curiosity. It would appear as though a robust and responsive network for connectivity is one of the key incentives for educators to embrace technology integration. On the other hand, the teachers' stories indicated that any lapse in either the hardware or the software derails the efforts to use interactive simulations, as lamented by the following teachers who bemoaned limited to variable access.

Bhonzo:

“We barely have enough computers for basic research, and the Wi-Fi? Forget it! It stutters like a nervous teenager on stage. It's all textbooks and worksheets here. I feel like I'm teaching the past using outdated tools.”

Bhonzo's school lacked sufficient resources. There were not enough computers even for basic research, and the Wi-Fi was unreliable. This limited Bhonzo to traditional methods like textbooks and worksheets, making them feel like they were teaching with outdated tools.

The frustration of **Dzasukwa** was palpable as he responded almost cynically:

“Sometimes requesting technology tools feels like flogging a dead horse! It seems not important to school leadership so why should I bother?”

Access to technology, in all its facets, is therefore a fundamental requirement when it comes to integration of interactive simulations in lessons. The above findings are borne out by Akbaşlı and Dönmez (2020) who note that facilitating conditions such as access to technology resources, significantly influence teachers' perceived ease of use and ultimately their behavioural intention to use technology. Means and Murphy (1993) also assert that limited access can lead to feelings of helplessness and frustration among teachers, hindering their sense of agency and ultimately impacting their willingness to explore technology integration.

The study showed that the modern classroom's potential for educational technology thrives in fertile ground nurtured by strong school support and robust infrastructure.

However, many schools face arid landscapes: inadequate funding, limited professional development, and unreliable internet hinder teacher adoption of interactive simulations. Strong leadership, dedicated resources, and reliable technology empower teachers like Mandireva to integrate simulations seamlessly, while limited access leaves Kabudura and Dzasukwa frustrated and resorting to traditional methods. Understanding this spectrum of support reveals critical factors influencing how science teachers utilise interactive simulations, paving the way for better equipping all educators to embrace technology and cultivate vibrant learning experiences.

4.3.3 Student Factors

The investigation into the factors influencing teachers' use of interactive simulations revealed a crucial player: the students themselves. Their characteristics and needs emerged as a powerful conductor, orchestrating the teacher's approach to integrating this technology.

On one hand, according to Mandireva and Hardlife, students with diverse learning styles, robust technology access at home, and familiarity with simulations provided fertile ground for seamless integration. Their adaptability, digital fluency, and prior experience resonated with the strengths of simulations, encouraging teachers to utilise them frequently and tailor them to individual strengths. For instance, visual learners readily absorbed information through dynamic visuals, kinaesthetic students revelled in the interactive nature, and students with strong technology skills navigated the platforms with ease. This positive feedback loop, where student engagement reinforced teacher use, created a harmonious learning environment where simulations flourished.

However, the teachers noted that not all students possessed the same technological instruments. Those with limited technology access at home or specific learning needs not well-supported by existing simulations presented contrasting challenges. Limited access required teachers to modify their plans, offering alternative activities or using simulations in small groups to ensure equitable participation. Similarly, specific learning needs, such as visual or auditory impairments, necessitated finding accessible simulations or developing supplementary materials to bridge the gap between the technology and the student's requirements. In these cases, teachers navigated a more complex terrain, carefully adapting their approach to ensure no student was left behind in the digital symphony.

The following are some of the responses to the interview question: How do you adapt your use of interactive simulations to accommodate students with different learning styles (e.g., visual, auditory, kinaesthetic)? Have you encountered any specific challenges in this regard?:

Mandireva:

"I try to find simulations with multiple interaction modes – visuals, audio descriptions, and manipulatable elements. For visuals, I pair up students with different strengths, letting them explain what they see to each other. I also encourage kinaesthetic learners to act out concepts learned through simulations in the classroom."

Mandireva recognised the importance of catering to different learning styles when using simulations. She looked for simulations that offered a variety of interactive features, including visuals, audio descriptions, and elements that students could manipulate. To make the most of the visuals, Mandireva paired students with different strengths, allowing them to explain their observations to each other. This encouraged collaboration and ensured everyone benefited from the visual aspects of the simulation. Additionally, Mandireva catered to kinaesthetic learners, those who learn best by doing, by having them act out the concepts they learned through the simulation. This hands-on approach helped solidify their understanding.

Chenzira:

"I usually stick to the built-in features of the simulations, hoping they cater to different learning styles. I try to explain things clearly verbally, maybe with some diagrams on the board, for those who need extra support."

Chenzira relied on the simulations themselves to accommodate different learning styles, hoping the built-in features were sufficient. She focused on clear verbal explanations, possibly using diagrams on the board, to provide additional support for students who needed it. This approach suggests Chenzira might not have been aware of the range of learning styles or lacked the time and resources to tailor activities for each style.

Bhonzo:

"Honestly, I don't have the time or resources to cater to every learning style. The simulations are what they are, and students just have to figure it out."

Bhonzo didn't feel that he had the extra time or resources to adjust lessons for every different way students learn. In their view, the simulations were what they were, and students had to manage on their own. This perspective suggests Bhonzo prioritized covering the curriculum content over individual learning styles. It is possible he felt overwhelmed by the workload or lacked the training to adapt activities for different learners.

The investigation into factors influencing teachers' use of interactive simulations in science revealed that teachers generally considered students with diverse learning styles, strong home technology access, and prior experience with simulations to be forthcoming in readily engaging with simulations, prompting more frequent, tailored use. Visual learners absorbed information through dynamic visuals, kinaesthetic learners thrived on the interactive nature, and tech-savvy students navigated platforms with ease. This positive feedback loop, where student engagement fuelled teacher use, created a vibrant learning environment where simulations flourished.

However, the teachers felt that not all students were equipped with the same tools. Those with limited technology access or specific learning needs presented challenges. Limited access required teachers to adapt, offering alternative activities or using simulations in small groups for equitable participation. Specific needs, like visual or auditory impairments, demanded finding accessible simulations or developing supplementary materials to bridge the gap. In these cases, teachers reported having to navigate a complex terrain, carefully adjusting their approach to ensure no student was left behind.

The above findings are supported by Sung and Mayer(2010) who posit that the interactive nature of simulations aligns with active learning and kinaesthetic approaches, while providing clear visuals for visual learners, act as push factors for teachers to integrate interactive simulations in their lessons more frequently. Miller & Wandersee (2017) also aver that students with visual and kinaesthetic learning styles tend to exhibit deeper understanding and improved problem-solving skills when using interactive science simulations compared to traditional instruction. This encourages the teachers to use simulations more frequently (Warschauer and Ames, 2018).

The findings as given by the interpretations of the teachers' responses discussed in section 4.3.3 above are backed by research, which highlights how student factors like learning styles and accessibility influence teacher approaches to integrating simulations (Sung & Mayer, 2010; Miller & Wandersee, 2017). By recognizing this spectrum of student readiness, teachers can fine-tune their use of simulations, creating an inclusive and impactful learning experience for all.

4.3.4 Teacher Beliefs, skills and Attitudes

Beyond the technology itself, a number of other factors shape how interactive simulations play out in the science classroom. This investigation revealed four crucial sets of Teacher Skills, Beliefs and Attitudes: attitudes and beliefs, time management and planning skills, curriculum and assessment practices, and classroom culture and learning environment. Each section's harmony or dissonance significantly impacts whether or not teachers integrate simulations, influencing student engagement and learning outcomes.

On the attitudes of teachers, it appeared as if those teachers with an open embrace of technology and a strong belief in simulations' educational value readily tuned their lessons to this innovative instrument. They appeared to see beyond challenges, maximizing simulations' potential. However, for those who appeared to harbour negative technology views or scepticism about simulations' effectiveness, they seemed less inclined to use the technology.

On planning, it appeared as though teachers with strong time management and organisational skills weaved simulations seamlessly into the curricular fabric. They planned effectively, navigated technical hurdles, and managed classroom time with precision. But for those with limited planning time or challenges managing classroom dynamics, integrating simulations appeared synonymous with chaotic improvisation, potentially compromising their effectiveness.

The teachers who were confident with simulations neatly matched them to their curricular goals effortlessly harmonised content and technology. However, when misalignment existed between curriculum and available simulations, teachers reported facing a discordant challenge, often needing to adapt or improvise, potentially impacting learning coherence.

Finally, some most teachers reported that classroom culture set the tone for them. Those that felt that their environments fostered collaboration and embraced technology, simulations resonated with both teachers and students. They became shared learning tools, enriching the educational experience. Conversely, in traditional classrooms with limited technology integration and a lack of collaboration, simulations seemed to struggle to find their voice, potentially amplifying existing inequities and dilating the digital divide. A wide range of answers were noted from the teachers in their response to the interview question: are there any perceived institutional or cultural barriers within your school system that may hinder the adoption of innovative teaching practices, such as the use of interactive simulations? Below are some of the responses given:

Hardlife:

"The curriculum feels rigid and doesn't always lend itself easily to incorporating simulations. Finding simulations that perfectly align with specific learning objectives can be challenging, and adapting them can raise concerns about coverage."

Hardlife found the curriculum to be inflexible, making it difficult to find simulations that perfectly matched specific learning objectives. Adapting simulations to fit the curriculum raised concerns about whether all the required content would be covered. This highlighted the need for curriculum materials that are more open to incorporating simulations and other technology-based learning tools.

Jekunareta:

"There's a bit of a 'if it ain't broke, don't fix it' mentality amongst some of my fellow teachers. Trying new things like simulations can feel like swimming against the current, and it can be discouraging when some colleagues are sceptical or hesitant."

Jekunareta observed a reluctance among some colleagues to embrace new approaches like simulations. She described it as an "if it ain't broke, don't fix it" mentality. This resistance, along with scepticism or hesitation from some teachers, could create a discouraging environment for those who want to integrate simulations. Addressing

these concerns through professional development and showcasing the effectiveness of simulations could help shift mindsets and encourage wider adoption.

Dzasukwa:

"We're already swamped with teaching, grading, and administrative tasks. Adding the learning curve of new tools like simulations feels overwhelming, especially without dedicated time or resources for integration. Who has the time or energy to learn all this new stuff? Simulating experiments won't magically improve my teaching evaluations. I'll mostly stick with what I know."

Dzasukwa felt overwhelmed by his existing workload, including teaching, grading, and administrative duties. The idea of adding new tools like simulations and figuring out how to integrate them into lessons felt like too much to handle, especially without any extra time or resources for learning how to do it effectively. Dzasukwa questioned whether the effort of learning new technology would be worth it, considering their performance evaluations wouldn't necessarily improve. This highlighted the importance of providing teachers with support when introducing new educational technology. Without dedicated time for training and clear guidance on integrating simulations effectively, teachers like Dzasukwa might be discouraged from venturing outside their comfort zones, even if they see the potential benefits.

In an effort to answer the sub-research question: what are factors that influence the use of interactive simulations by science teachers?, this research unearthed a range of perspectives from teachers regarding potential institutional or cultural barriers to adopting innovative teaching practices like simulations which they face. These included concerns about rigid curriculum constraints, resistance to change among colleagues, standardised test pressure, and limited professional development or support. Interestingly, some teachers expressed scepticism about the technology itself, citing concerns about student distraction or questioning the overall value of simulations compared to traditional methods.

The findings outlined as additional factors are supported by the research conducted by Sung and Mayer (2010), and Moore, Cheng, Peck, and Zhou (2018), who show that teachers with open minds towards technology and strong convictions about simulations' educational value readily integrate them in their lessons. They see beyond challenges,

maximising simulations' potential. However, scepticism or negative technology views, as explored by Fives & Buehl (2012), can lead to disharmony, hindering integration. Warchauer & Ames (2018) and Miller and Wandersee (2017), highlight the importance of strong time management and organizational skills. Teachers who plan effectively, navigate technical hurdles, and manage classroom time with precision, like conductors with a well-rehearsed score, weave simulations seamlessly into the curricular fabric. But for those with limited planning time or challenges managing classroom dynamics, this can feel like chaotic improvisation, potentially compromising effectiveness and integration (Proctor, Burggren, and Smith, 2013). Wang, Sun, and Chen (2019) emphasise that teachers with simulations neatly matched to their curricular goals are able to harmonise content and technology effortlessly. However, when misalignment exists, as Sanger and Greenbowe (2011) discuss, teachers face a discordant challenge, often needing to adapt or improvise, potentially impacting learning coherence. Chin and Gillis (2015) further highlight the role of assessment practices in this alignment, suggesting that teachers' beliefs about assessment and the compatibility of simulations with existing assessment methods influence their integration decisions. In environments that foster collaboration and embrace technology, simulations resonate with both teachers and students (Eury and Pea, 2014). Interactive simulations become shared learning tools, enriching the educational experience. Conversely, in traditional classrooms with limited technology integration and a lack of collaboration, as explored by Yousef & Al-Banna (2012), interactive simulations may struggle to find their voice, potentially amplifying existing inequities.

4.3.5 A summary of factors that influence the use of interactive simulations by science teachers.

To answer the sub-research question: **what are the factors that influence the use of interactive simulations by science teachers to foster critical thinking skills?**, the factors that emerged included the multifaceted concept of teacher knowledge and skills. A harmonious blend of strong technological understanding, pedagogical expertise, deep content knowledge, and the ability to blend them seamlessly through TPACK emerges as the key catalyst for frequent and effective integration of simulations. Conversely, limited technology access, traditional teaching preferences, curriculum misalignment, and inadequate understanding of how to leverage simulations for deeper learning act as dissonant notes, impeding their utilisation. Robust leadership, dedicated funding for resources, and readily available professional

development opportunities amplify the teachers' inclination to integrate simulations. Conversely, inadequate funding, limited professional development options, and unreliable technology infrastructure act as dampeners, stifling the potential for technology-driven learning. Diverse learning styles, strong home technology access, and prior experience with simulations act as vibrant incentives, encouraging teachers to tailor their use of simulations and maximise their potential. However, limited technology access or specific learning needs not well-supported by existing simulations introduce potential barriers, necessitating adaptations and careful planning to ensure inclusivity and equitable learning experiences. Teachers' open attitudes towards technology and belief in simulations' value act as pull factors, while scepticism and limited time management skills breed inertia toward use of interactive simulations. Curriculum alignment and assessment practices influence the coherence and effectiveness of simulation integration. Lastly, the classroom culture, determines whether simulations resonate harmoniously or remain muted echoes in the traditional pedagogical landscape.

4.4 Perceptions of science teachers on the use of interactive simulations to foster critical thinking skills.

This study delved into the nuanced world of science teachers' perceptions regarding the use of interactive simulations for fostering critical thinking skills in their students. The study probed beyond simplistic pronouncements of "effective" or "ineffective" to uncover the rich tapestry of opinions, concerns, and experiences held by educators on the frontlines of education. By examining their views on the strengths and limitations of simulations, their understanding of how these tools can be leveraged for critical thinking development, and the challenges they face in implementing them effectively, the study aimed to provide a more comprehensive understanding of this intricate relationship. By amplifying the voices of science teachers and examining the complexities of their experiences, the study hoped to inform pedagogical practices, develop targeted support mechanisms, and pave the way for the effective utilisation of simulations in fostering critical thinking skills in future generations of science teachers in South Africa.

Analysis of the findings are given in the table 4.4 below which displays a summary of the perceptions of science teachers on whether or not the use of interactive simulations

fosters critical thinking skills. Table 4.4 also provides a summary of the themes that emerged from the analysis of the science teachers' views. The views expressed by the majority of the respondents pointed to the conviction that interactive simulations do foster critical thinking in students. Even the teachers with low technological knowledge appeared to lauded the power of interactive simulations to develop critical thinking skills. Although two of the educators were sceptical, and one was unsure of how interactive simulations can be credited for fostering critical thinking skills, it was interesting to note that none of the teachers gave a view completely opposed to such efficacy of interactive simulations. The teachers' perceptions seemed to be informed by the level of understanding of what critical thinking skills are and how they manifest in students. These diverse perspectives illustrated how critical thinking can be defined and implemented in science education using interactive simulations, showcasing the richness and versatility of this pedagogical approach. Each teacher's unique vision highlighted the importance of fostering independent thought, problem-solving skills, and a questioning spirit in our future generation of scientists, science teachers, engineers and other domains in general.

Table 4.4 Science Teachers' Perceptions on Using Interactive Simulations for Critical Thinking Skills

Theme - factor	Teachers Who Believed Simulations Promote Critical Thinking	Teachers Unsure About Impact on Critical Thinking	Teachers Who Doubted Simulations Foster Critical Thinking
Skills Development (TPCK)	Simulations can foster specific critical thinking skills through interactive elements and scenarios.	Simulations might develop critical thinking, but research on specific skill development is needed.	Simulations are limited in developing critical thinking. It's hard to isolate this skill from technology and teaching methods.
Engagement & Motivation (TPK)	Well-designed simulations increase student engagement in critical thinking activities.	Engagement depends on student preferences and simulation design's alignment with critical thinking tasks.	Poor design or implementation can lead to disengagement, hindering critical thinking.
Assessment & Data (TCK & PCK)	Simulations provide rich data on student critical thinking processes through interaction and decision-making.	Isolating critical thinking from other factors influencing data is difficult, making assessment of specific skill growth challenging.	Lack of valid & reliable assessment tools for critical thinking within simulations limits evaluation of skill development.
Curriculum Integration (TPK & PCK)	Simulations align well with inquiry-based and active learning that promote critical thinking.	Careful planning and adaptation are required to ensure simulations effectively target critical thinking skills within the curriculum.	Simulations are difficult to integrate if the curriculum lacks alignment with the simulations' critical thinking goals.
Bias & Equity (TPCK & PCK)	Simulations can promote access to diverse perspectives and ethical considerations, encouraging critical thinking about complex topics.	Simulations might reinforce biases and exclude marginalized groups if not designed inclusively, impacting critical thinking development.	Simulations can exacerbate existing inequities in access to critical thinking opportunities if not used thoughtfully and with critical reflection on bias and inclusivity.
Openness & Scepticism (TK & TPK)	Teachers are open to trying simulations with support and evidence of their effectiveness in promoting critical thinking.	More research and evidence-based practices are needed to address scepticism about simulations' impact on critical thinking development.	Teachers are sceptical due to: lack of awareness about newer simulations designed for critical thinking, negative past experiences, or concerns about overall effectiveness.
Technical & Resource Considerations (TK & TPCK)	Efficiency and accessibility can enable wider student engagement in critical thinking activities within simulations.	Technical difficulties and resource limitations can hinder access to and effectiveness of simulations for critical thinking development.	Technical difficulties, resource limitations, and student engagement issues are insurmountable, limiting the potential of simulations.

4.4.1 Skills Development

The research data on the science teachers' perceptions regarding the ability of interactive simulations to foster critical thinking skills presented a mixed picture, highlighting both promising potential and significant challenges. The majority of the teachers reported a positive outlook stemming from the immersive nature of simulations, which they deemed capable of providing opportunities for students to practise and develop specific critical thinking skills like data analysis, problem-solving, and questioning. Further, the respondents perceptions were that by engaging with scenario-based challenges and exploring various options, students could build crucial competencies in areas like hypothesis testing, evidence evaluation, and decision-

making under uncertain circumstances. However, some teachers were of the neutral stance that acknowledges the lack of robust evidence confirming the true effectiveness of simulations in building critical thinking skills. Isolating the specific impact of simulations from other factors, such as curriculum design, teaching methods, and individual student characteristics, were some of the challenges raised by the teachers. The neutral teachers advocated for further research with rigorous methodologies in order to establish a clear link between simulations and critical thinking skills development. Negative perspectives were also raised around the limited effectiveness of some simulations and the potential for amplifying existing biases, particularly for vulnerable groups. The teachers concurred that simulations designed without careful consideration of diverse perspectives and inclusivity could inadvertently reinforce prejudices and hinder critical thinking, especially for students already facing inequalities in educational opportunities.

Once again, the interplay between content knowledge (CK), Pedagogical knowledge (PK), and Technological knowledge was brought to the fore. The perceptions were clearly informed by each individual teacher's understanding of critical thinking skills and their competence in deploying the interactive simulations to serve a set of clearly defined curriculum objectives. Where the objectives were hazy or the technological efficacy was iffy, the perceptions were dim. Some insights can be drawn from the teachers' responses to the questions: *How do you personally define critical thinking in the context of science education, and how does this definition influence your instructional strategies with interactive simulations?*

Mandireva:

"Critical thinking in science for me is like peeling an onion. You start with the surface details, the observations from experiments or simulations, and then you keep questioning, digging deeper to uncover the connections, biases, and assumptions. My interactive simulations become onion-peeling tools. We analyse data trends, compare scenarios, and test alternative explanations until we reach a core understanding that's not just memorisation, but an active construction of knowledge."

Mandireva saw critical thinking as a process of uncovering layers of understanding, like peeling an onion. Simulations became tools for students to analyse data, compare scenarios, and question assumptions to build a deeper understanding of scientific concepts, not just memorise them.

Chenzira:

"For me, it's all about asking the right questions. Critical thinking means not just accepting what simulations show, but questioning their limitations, the underlying models, and even the design choices. In my physics class, we use simulations as springboards for debate, challenging each other's interpretations and exploring the 'what ifs' beyond the screen. It's messy, but it sparks curiosity and genuine engagement."

Chenzira focused on questioning. For her, critical thinking meant going beyond what simulations showed and examining their limitations, underlying models, and design choices. She used simulations to spark debate and explore alternative explanations, encouraging a "messy" but thought-provoking learning environment.

Kabudura:

"Critical thinking in science can't be divorced from real-world contexts. So, I use simulations as launching pads for students to identify biases, consider ethical implications, and connect scientific concepts to social issues. We explore simulations of climate change, pollution, and healthcare, encouraging them to think critically about how science interacts with society and their own lives."

Kabudura emphasized the connection between science and the real world. He used simulations to launch discussions about bias, ethics, and the social implications of science. These simulations explored topics like climate change, pollution, and healthcare, encouraging students to think critically about the role of science in society.

Hardlife:

"For me, critical thinking is making science accessible to every learner. I use simulations with multiple accessibility features, scaffolds, and differentiated tasks to empower all students to question, explore, and analyse data. It's about building confidence in their own thinking, not just conforming to a single right answer. Every click, drag, and observation becomes a step towards their unique understanding."

Hardlife viewed critical thinking as making science accessible for all learners. He used simulations with accessibility features, scaffolds, and differentiated tasks to empower students to question, explore data, and build confidence in their own thinking, not just find a single "right" answer.

Mushamba gave a more detailed and nuanced response when he said:

"For me, critical thinking in science education isn't just about learning facts; it's about learning to think like a scientist. It's about questioning everything, analysing evidence with a discerning eye, and constructing robust arguments based on data. It's not about following a pre-programmed path, but about navigating uncertainties and complexities with intellectual courage and flexibility. Now, while I see some potential in interactive simulations, I have reservations about their ability to truly foster this kind of critical thinking. Firstly, many simulations present a narrow world, focusing on specific scenarios that limit opportunities for broader application and transfer of skills. They can feel like closed ecosystems, offering limited scope for the kind of open-ended inquiry and argumentation that fuel genuine critical thinking. Secondly, the very nature of simulations, with their built-in pathways and outcomes, can be a double-edged sword. While they may provide structure and engagement, they can also lure students into a false sense of accomplishment. It's easy to breeze through a simulation, following the prompts, and feeling like you've "done" critical thinking, when in reality, you've just navigated a pre-determined course. Thirdly, I worry that over-reliance on technology can undermine the fundamental skills of critical thinking. Simulations can present information visually and interactively, which is great for engagement, but it can also lead

to superficial understanding if students aren't challenged to dig deeper, question assumptions, and build their own arguments based on evidence. So, how do I approach simulations in my classroom? Well, with caution and critical engagement. I use them as tools to spark curiosity and provide context, but not as the sole driver of critical thinking development.

Mushamba offered a more critical perspective. While acknowledging the potential of simulations, he expressed concerns about their ability to truly foster critical thinking. He argued that simulations often present a limited world with narrow scenarios, hindering the transfer of critical thinking skills to broader contexts. Additionally, Mushamba worried that the built-in pathways and outcomes of simulations could create a false sense of accomplishment, leading students to believe they have thought critically when they have simply followed a predetermined course. Finally, he expressed concern that over-reliance on the visual and interactive nature of simulations could lead to superficial understanding if students were not challenged to question, analyse evidence, and build their own arguments. Mushamba used simulations cautiously, viewing them as tools to spark curiosity and provide context, not the sole driver of critical thinking development.

The mixed perceptions highlighted reflect both promise and challenges regarding interactive simulations' ability to foster critical thinking skills. Careful design, research, and pedagogical strategies are crucial to maximise their potential while mitigating risks. The positive perceptions are in agreement with the views of Akerson, and Donnelly, (2010) who highlight the immersive nature of simulations and their ability to promote inquiry-based learning, which can foster critical thinking skills. Abrahams and Reiss (2006) argue that simulations based on science fiction scenarios can encourage critical thinking through questioning, analysis, and problem-solving. The neutral to negative perceptions are also supported by Cook and Metz (2014) who highlight the difficulty of isolating the impact of educational games, including simulations, on specific cognitive skills like critical thinking. Shute and Kegelmeyer (2013) argue that not all virtual learning environments, including simulations, are equally effective in promoting desired learning outcomes, including critical thinking. Su and Grady (2017) warn about the potential for educational technology, including simulations, to inadvertently reinforce existing biases and contribute to educational inequities. The sub-research

question: what are the perceptions of science teachers on the use of interactive simulations to foster critical thinking skills?, remains moot at this point.

4.4.2 Engagement and Motivation

Analysis of the teachers' responses showed that interactive simulations can have a positive impact on critical thinking when they effectively engage students in critical thinking activities. However, their impact can be neutral or negative if the design fails to promote engagement or disengages students through poor implementation. This was revealed by their responses to the interview question: in your opinion, *what role do interactive simulations play in developing students' metacognitive skills, particularly their ability to reflect on and regulate their own thinking processes?*, to which some responded:

Mandireva:

"Simulations are like magic in my classroom! They hook students' engagement from the get-go, letting them manipulate molecules and see reactions unfold in real-time. This active engagement sparks curiosity, and as they experiment and observe, they naturally start reflecting on their predictions, analysing their reasoning, and tweaking their approaches. It's like watching their metacognition muscles grow right before my eyes! But it's not just about flashy graphics, the best simulations have built-in reflection prompts and feedback loops that guide students towards deeper self-regulation of their learning, that there, eh, is critical thinking for me."

Mandireva saw simulations as magical tools that grabbed students' attention from the start. Students manipulated elements and saw reactions in real-time, sparking curiosity and active exploration. This led to natural reflection on predictions, analysis of reasoning, and adjustments in approach. Mandireva viewed the development of these "metacognition muscles" as a sign of critical thinking. However, she emphasised that effective simulations went beyond flashy graphics and included built-in reflection prompts and feedback loops. These features guided students towards deeper self-regulation of their learning, which Mandireva equated with true critical thinking.

Kabudura:

"I'm all for student engagement, but I worry simulations can be a distraction for metacognition. Sure, they're fun, but do they really push students to think critically? In physics, I find Socratic questioning and collaborative problem-solving activities far more effective. They force students to articulate their reasoning, confront misconceptions in real-time, and learn from each other's approaches. That's where the true magic of metacognition happens – students actively constructing and refining their understanding through engaged dialogue."

Kabudura, while acknowledging the engagement benefits of simulations, expressed concern that they could distract from true metacognition. He questioned if simulations really pushed students to think critically. In his physics class, Kabudura found Socratic questioning and collaborative problem-solving activities to be more effective. These activities forced students to explain their reasoning, confront misconceptions on the spot, and learn from each other's approaches. This, according to Kabudura, is where the magic of metacognition happened, students actively built and refined their understanding through engaged dialogue.

Chenzira:

"Interactive simulations are a game-changer for student engagement in complex biological concepts! Imagine dissecting a virtual frog or simulating an ecosystem – these experiences grab their attention and make abstract processes tangible. But the real power lies in the reflection prompts and analysis tools embedded within. Students can compare their predictions to outcomes, analyse data visualizations, and adjust their models based on new evidence. This iterative cycle of engagement, reflection, and refinement is pure metacognitive gold!"

Chenzira saw interactive simulations as a game-changer for student engagement with complex concepts. She highlighted the power of virtual experiments and simulated reactions in making abstract processes tangible and grabbing students' attention. However, Chenzira, like Mandireva, stressed the importance of reflection prompts and

analysis tools embedded within the simulations. These features allowed students to compare their predictions to actual outcomes, analyse data visualisations, and adjust their models based on new evidence. Chenzira viewed this iterative cycle of engagement, reflection, and refinement as the key to fostering metacognition.

Jekunareta:

"Simulations can be a powerful tool for student engagement, but their impact on metacognition depends on design and implementation. Cookie-cutter simulations with predetermined outcomes can be entertaining, but they don't encourage students to question, analyse, or regulate their own thinking. The key is to use simulations as springboards for open-ended inquiry and collaborative problem-solving. When students are actively engaged in constructing and refining their understanding, they naturally develop the critical metacognitive skills needed to navigate complex scientific concepts."

Jekunareta offered a balanced perspective. She acknowledged the potential power of simulations for student engagement but argued that the impact on metacognition depended heavily on design and implementation. Jekunareta cautioned against simulations with predetermined outcomes, which might be entertaining but wouldn't encourage students to question, analyse, or regulate their own thinking. The key, according to Jekunareta, was to use simulations as springboards for open-ended inquiry and collaborative problem-solving. When students were actively engaged in constructing and refining their understanding, they naturally developed the critical metacognitive skills needed to navigate complex scientific concepts

The theme emphasises the importance of thoughtfully designed and implemented technological interventions, informed by TPK, to optimize student engagement and unlock the potential of technology for fostering critical thinking skills. However, recognising individual preferences and addressing potential pitfalls remain crucial for ensuring technology serves as a true catalyst for meaningful learning. The above findings resonate with those of other researchers. Effective use of interactive simulations cultivates an environment where students actively engage in the construction of knowledge through critical thinking activities (Voogt, Dede, and Mishra, 2013; Mishra & Koehler, 2009). Akyol and Yalcin (2015) also echo the

cautious words of one of the teachers when they assert that poorly designed simulations lacking open-ended exploration can lead to disengagement and hinder critical thinking skills.

4.4.3 Assessment and Data

The respondents voiced their discomfort with assessment of critical thinking skills. They acknowledged that simulations offer rich data on student interactions and decisions, potentially revealing their critical thinking processes. However, isolating and accurately assessing specific critical thinking skills within this data remains challenging. Their concerns agreed with the research findings of Moss, Williamson and Downes (2015) who highlight the challenge of disentangling critical thinking skills from other cognitive processes and domain knowledge reflected in simulation data. A more in-depth analysis of the on assessment of critical thinking skills will be examined under the findings on the next research question.

4.4.4 Curriculum Integration

Although the teachers cited major challenges with integrating interactive simulations into the curriculum, there was near unanimity that thoughtfully integrating simulations into the curriculum presents a valuable opportunity to cultivate critical thinking skills through engaging and active learning experiences. Success hinges on careful planning, curriculum alignment, and leveraging TPK and PCK expertise.

The findings are borne out by the research on situated learning, which suggests that simulation-based environments can promote critical thinking through exploration, problem-solving, and collaboration provided there is alignment between curriculum goals and critical thinking objectives of the simulation (Dede, Mishra, and Ferguson, 2016; Akaydin and Yildirim, 2014). Conversely, teachers' lack of technological pedagogical content knowledge (TPACK) can lead to challenges in effectively integrating technology, like simulations, into the curriculum (Mishra & Koehler, 2006)

4.4.5 Bias and Equity

A common thread that ran through the narratives of the teachers was that well-designed simulations can promote critical thinking about complex topics in science by showcasing diverse perspectives and ethical considerations. This exposure can encourage students to critically examine their own biases and develop a more nuanced understanding of the world. On the other hand, the teachers underscored the risk of

poorly designed simulations to inadvertently reinforce existing biases and exclude marginalised groups, such as those without access at home or lack prior knowledge on the use of technology, thereby hindering critical thinking development for diverse learners. Limited access to technology and simulations, they also pointed out, can potentially exacerbate existing inequities in critical thinking opportunities. The findings are supported by Moss, Williamson and Downes (2015) who highlight the challenge of ensuring simulations don't reinforce existing biases or privilege certain perspectives, potentially hindering critical thinking development for diverse learners. Niess (2015) emphasises the importance of teacher awareness of digital equity issues and ensuring all students have access to technology and support needed to fully engage with simulations. Kozol (2013) also critiques the potential of technology to exacerbate existing educational inequalities, particularly when access to technology and opportunities for critical thinking through its use are unevenly distributed.

4.4.6 Openness and Scepticism

The teachers decried the lack of information providing evidence of the effectiveness of interactive simulations in promoting critical thinking skills which could encourage them to approach such technology with an open mind. The teachers indicate that such openness requires ongoing research and the development of evidence-based practices to validate the impact of simulations on critical thinking development. In the absence of such research based evidence, the teachers maintained that the use of interactive simulations remained experimental and therefore not essential. It also emerged that some teachers regard interactive simulations with scepticism owing to negative past experiences with poorly designed simulations that failed to deliver on their promises.

Koehler, Mishra, Shulman, Ainley and Darling-Hammond (2014) concur with the findings as they advocate for design research and collaboration between educators and researchers to refine and validate technology-based learning environments like simulations, ensuring they align with learning goals and promote desired skills like critical thinking. Clark & Kirschner (2014) also point out the potential for poorly designed simulations to hinder learning and reinforce negative perceptions of technology in education, contributing to educator scepticism towards new technology like simulations. Shute and Pellegrino (2012) also emphasise the importance of considering the design features and implementation strategies of simulations when

evaluating their effectiveness, as negative experiences with poorly designed or implemented simulations can lead to understandable scepticism.

4.4.7 **Technical & Resource Considerations**

While acknowledging the potential for wider engagement and efficiency in the use of interactive simulations, technical and resource limitations continue to present significant challenges according to the teachers as discussed in section 4.3.1.2. The perception of the teachers was that well-designed interactive simulations hold significant potential to foster critical thinking skills, technical and resource limitations can hinder access and effectiveness. The findings under this theme are supported by Niess (2015) who highlights teacher concerns about limited access to technology and resources, which can hinder equitable access to and effectiveness of simulations for critical thinking development. Clark & Kirschner (2014) point out that inherent limitations in technology and access can impede the potential of innovations like simulations to fully deliver on their promises. Shute and Pellegrino (2012): emphasize the importance of considering technical aspects and implementation strategies when evaluating the effectiveness of simulations, as limitations can negatively impact learning outcomes.

To answer the sub-research question: **what are the perceptions of science teachers on the use of interactive simulations to foster critical thinking skills?**, the research found multiple factors chief among which were around the teachers' TPACK competences or self-efficacy, curriculum alignment in terms of pedagogy and assessment for critical thinking, administrative policies and technological resources, teacher beliefs and learner needs and finally, the need for simulation-specific assessments. Hierarchically, the positive perceptions were that interactive simulations are effective in fostering critical thinking skills, that they facilitate student engagement and motivation. On the other hand, the perceptions were that interactive simulations need a lot of expertise and time to align with the curriculum and to find suitable assessments that match the learning goals with critical thinking objectives. There were concerns that interactive simulations can potentially widen the digital gap and thus reinforce the biases and inequities inherent within different socio-economic groups. The lack of research on the efficacy of interactive simulations also fuelled resistance of some teachers not to integrate interactive simulations in their science lessons as they did not see the pedagogical value of such instructional tools.

4.5 Methods used by science teachers to assess critical thinking skills

This research investigated the methods employed by science teachers to assess their students' critical thinking skills. The analysis, informed by themes identified through a cross-table analysis of various assessment practices, TPACK dimensions, and targeted critical thinking skills, reveals insights into the current landscape of critical thinking assessment in science education. Table 4.5 below highlights the recurring methods as captured from the teachers. In order to give the methods weight and relevance, the specific critical thinking skills purportedly measured, the perceived advantages and disadvantages as well as specific assessment practices for each method were identified.

Table 4.5: Analysis of Assessment Methods for Critical Thinking in science				
Assessment Method	Type of Critical Thinking Skills Assessed	Advantages	Disadvantages	Specific Assessment Practices
Formal Assessments				
Standardised tests	Analysis, evaluation, inference	Standardised, objective data	Limited scope, may not capture all critical thinking skills	CER-based questions, open-ended prompts
Traditional exams	Analysis, explanation, comparison	Can assess multiple skills, familiar format for students	May prioritise memorisation over understanding, limited opportunities for open-ended thinking	Higher-order thinking questions, essay prompts requiring application of concepts
Performance-based assessments	Application, problem-solving, creativity	Authentic, engaging for students	Can be time-consuming to grade, may require specialised resources	PBL projects, science fairs, designing experiments
Informal Assessments				
Classroom discussions	Analysis, evaluation, argumentation	Can assess higher-order thinking skills, promotes active learning	Requires skilful facilitation, may not be equally accessible to all students	Socratic Seminars, concept maps, debates
Observations	All critical thinking skills	Provides real-time insights, can identify individual needs	Subjective, may be influenced by teacher bias	Think-alouds, peer review, exit tickets with metacognitive prompts
Exit tickets/reflections	Analysis, evaluation, self-assessment	Quick and efficient, provides feedback for both teacher and student	Limited scope, may not be reliable measures of understanding	CER frameworks, claim-evidence-reasoning prompts
Additional Practices				
Concept-Focused				
Venn diagrams, concept maps	Analysis, comparison	Visual representation supports understanding of relationships	May be time-consuming, relies on student organisation	
Claim-Evidence-Reasoning (CER) Frameworks	Synthesis, argumentation	Explicit focus on scientific reasoning	Can be challenging for lower-level students	
Application-Focused				
Case studies, problem-based learning	Application, problem-solving, decision-making	Real-world context promotes engagement	Requires careful selection of appropriate scenarios	
Scientific debates	Argumentation, critical analysis	Fosters critical thinking through opposing viewpoints	Requires classroom management skills, may not suit all topics	
Metacognitive Practices				
Learning journals, peer review	Self-reflection, evaluation	Promotes metacognitive awareness, collaboration	Requires time for reflection and feedback	
‘Think-alouds’	Problem-solving strategies, reasoning processes	Provides insights into student thinking	Can be disruptive to classroom flow, requires student comfort with verbalising thoughts	

Further analysis of the assessment methods revealed five themes: Moving Beyond Recall, Balancing Assessment Scope, Promoting Metacognition, Importance of Context and Engagement, Teacher Facilitation and Skill Development. Table 4.6 below summarises these themes. More insights about each theme are provided in the discussion that follows.

Table 4.6: Themes on Assessment methods for critical thinking skills.

Theme - Factor	Assessment Method	Type of Critical Thinking Skills Assessed	TPACK Dimensions	Specific Assessment Practices
Moving Beyond Recall	Traditional exams (higher-order questions), Performance-based assessments, Concept-focused practices (Venn diagrams, CER frameworks), Application-focused practices (case studies, PBL)	Analysis, explanation, comparison, application, problem-solving, creativity	TK, PCK, CK, TPACK	Essay prompts, PBL projects, science fairs, concept maps
Balancing Assessment Scope	Standardised tests, Traditional exams, Exit tickets/reflections	Analysis, evaluation, inference	TK, PCK	CER-based questions, open-ended prompts, claim-evidence-reasoning prompts
Promoting Metacognition	Informal assessments (observations, exit tickets/reflections), Metacognitive practices (learning journals, peer review, 'think-alouds')	All critical thinking skills, self-reflection, evaluation	PCK, CK	'Think-alouds', learning journals, metacognitive prompts
Importance of Context and Engagement	Informal assessments (classroom discussions, debates), Application-focused practices (case studies, PBL)	Analysis, evaluation, argumentation, application, problem-solving, decision-making	PCK, CK, TPACK	Socratic Seminars, debates, PBL projects, science fairs
Teacher Facilitation and Skill Development	Informal assessments (observations), Metacognitive practices (learning journals, peer review)	All critical thinking skills, self-reflection, evaluation	PCK, CK	Observations, feedback on learning journals, facilitating discussions

4.5.1 Moving Beyond Recall

The findings emphasise a shift towards assessments that go beyond mere factual recall, prioritising higher-order skills like analysis, evaluation, application, and problem-solving. This trend is evident in practices like essay prompts in traditional exams, PBL projects, and concept maps.

Responding to the question: do you employ any formative assessment techniques to continuously gauge students' critical thinking development throughout the course of the year? What are some of your techniques?, here is what some of them had to say:

Mushamba:

"I design open-ended lab reports where students analyse data, draw conclusions, and explain their findings using evidence. It's amazing to see them grapple with complex concepts and develop their scientific reasoning skills."

Mushamba designed open-ended lab reports. These reports required students to analyse data, draw conclusions, and explain their findings using evidence. This process involved students dealing with complex ideas and developing their scientific reasoning skills as they sought explanations for their observations.

Bhonzo:

"Instead of traditional tests, I create problem-solving challenges that require students to apply their knowledge to novel situations. It's exciting to watch them brainstorm creative solutions and justify their approaches, showcasing their critical thinking in action."

Bhonzo replaced traditional tests with problem-solving challenges. These challenges forced students to apply their knowledge to new situations. The excitement Bhonzo described suggested these challenges sparked creative thinking and required students to justify their approaches, demonstrating their critical thinking abilities in action.

Hardlife:

"I love using concept maps with my students. They visually connect ideas, identify gaps in understanding, and revise their thinking based on new information. It's a dynamic process that fosters critical thinking and active learning."

Hardlife embraced concept maps. Students used these maps to visually connect ideas, identify areas where their understanding was weak, and revise their thinking based on new information. This dynamic process, according to Hardlife, fostered critical thinking and active learning as students constantly built upon and refined their understanding of scientific concepts.

A key finding of this research is the emphasis on assessing higher-order critical thinking skills through various methods. Traditional exams are evolving, incorporating higher-order thinking questions that require students to analyse, explain, and compare concepts. Similarly, performance-based assessments, like Project Based Learning (PBL) projects and science fairs, demand application, problem-solving, and even creativity. These findings directly address the research question, "What are the methods used by science teachers to assess critical thinking skills?" They demonstrate that teachers are employing a diverse range of methods that move beyond recall and delve deeper into the analysis, evaluation, application, and problem-solving abilities that define critical thinking. By employing multiple knowledge domains (TK, PCK, CK, TPACK) through these varied assessment practices, science teachers are creating a

richer picture of their students' critical thinking abilities. This comprehensive approach provides valuable insights into student understanding and informs effective future instruction. The research reveals a promising shift in science education towards assessing critical thinking as a core skill. The diverse methods employed, exemplified by the "Moving Beyond Recall" theme, demonstrate a commitment to nurturing analytical, creative, and problem-solving minds in the next generation of scientists.

4.5.2 Balancing Assessment Scope

While some assessments, like standardized tests, offer broader coverage, others delve deeper into specific skills. The challenge lies in finding a balance between breadth and depth to ensure a comprehensive evaluation of critical thinking. Assessing a broad range of critical thinking skills while also diving deep into specific areas remains a challenge for science teachers. Responding to the question: do you employ any formative assessment techniques to continuously gauge students' critical thinking development throughout the course of the year? What are some of your techniques?, here is what some of them had to say:

Chenzira:

"I combine standardized tests with mini-research projects throughout the year. The tests offer a broad overview of knowledge, while the projects allow me to delve deeper into specific skills like research, analysis, and argumentation."

Chenzira combined standardised tests with mini-research projects throughout the year. While standardised tests provided a broad picture of students' knowledge base, the mini-research projects allowed Chenzira to assess specific skills like research, analysis, and argumentation. These projects required students to dig deeper into scientific concepts, analyse information, and build a well-reasoned argument, showcasing their critical thinking abilities.

Jekunareta:

"I use CER (Claim, Evidence, Reasoning) frameworks throughout the year. They're embedded in classroom discussions, quizzes, and even final projects. This consistent focus on scientific reasoning ensures thorough assessment of critical thinking across different contexts."

Jekunareta implemented the CER (Claim, Evidence, Reasoning) framework throughout the year. This framework was embedded in classroom discussions, quizzes, and even final projects. Jekunareta's consistent focus on CER ensured a thorough assessment of critical thinking skills across different contexts. By requiring students to develop claims, support them with evidence, and explain their reasoning, Jekunareta could gauge their ability to think critically and construct logical arguments based on scientific knowledge.

This research highlights the ongoing effort to balance assessment scope through diverse methods. On one hand, teachers are using tools like standardized tests which paint a wider picture of student performance across various critical thinking abilities. Conversely, practices like Claim-Evidence-Reasoning (CER) based prompts and exit tickets focus on specific skill sets, allowing for a more nuanced understanding of those areas. This balancing act is crucial to ensure a comprehensive evaluation of critical thinking. By utilizing both broad and targeted assessments, teachers are gaining valuable insights into students' strengths and weaknesses across the spectrum of critical thinking skills. This research sheds light on the importance of finding the right balance between assessing the breadth and depth of critical thinking skills. By employing a variety of tools and approaches, science teachers can gain a more complete and nuanced understanding of their students' critical thinking abilities, ultimately supporting their growth and development in this vital area.

4.5.3 Promoting Metacognition

This research highlights a crucial aspect of assessing critical thinking: fostering metacognition. Beyond simply measuring what students know and can do, science teachers are increasingly focusing on how students think. Responding to the question: do you employ any formative assessment techniques to continuously gauge students'

critical thinking development throughout the course of the year? What are some of your techniques?, here is what some of them had to say:

Mushamba:

"Learning journals are a game-changer. Students reflect on their thinking process, identify challenges, and set goals for improvement. This self-awareness is crucial for fostering critical thinking and developing independent learners."

Mushamba found learning journals to be a game-changer. Students used these journals to reflect on their thinking processes, identify challenges they faced, and set goals for improvement. This focus on self-awareness, according to Mushamba, was essential for fostering critical thinking and developing independent learners. By reflecting on their thought processes, students were better able to identify areas where they needed to strengthen their understanding and take ownership of their learning.

Bhonzo:

"Think-alouds are amazing! Students verbalize their thought process as they solve problems, allowing me to identify misconceptions and provide targeted support. It's all about guiding their critical thinking development, not just giving them answers."

Bhonzo championed think-alouds as a powerful tool. This strategy involved students verbalising their thought process as they solved problems. Bhonzo explained that listening to students think aloud allowed them to identify misconceptions and provide targeted support. The focus, according to Bhonzo, was on guiding students' critical thinking development, not simply providing them with answers. By encouraging students to articulate their thought processes, Bhonzo could identify areas where they struggled and offer specific guidance to help them develop their critical thinking skills.

Kabudura:

"Peer review activities are fantastic! Students analyse each other's work, offer constructive feedback, and justify their reasoning. This collaborative process not only hones critical thinking skills but also promotes communication and self-reflection."

Kabudura saw peer review activities as a great way to promote critical thinking and collaboration in science classrooms. Students were not just passively looking at each other's work; they were actively analysing it, offering constructive feedback, and justifying their reasoning. This process of critiquing and explaining their thinking forced students to analyse the material more deeply, strengthening their own critical thinking skills. Students also received feedback, which encouraged them to develop strong communication skills as they explained their work to peers. Moreover, receiving feedback prompted students to reflect on their work from a different perspective, potentially leading to deeper self-reflection and improvement. Overall, peer review activities fostered a collaborative learning environment where students were not just learning in isolation; they were learning from and with each other.

The findings reveal the importance of methods that encourage students to reflect on their own thinking processes. This "thinking behind the thinking" is key to developing self-directed learners and critical thinkers. Observations, for example, allow teachers to witness students' problem-solving strategies and identify areas where metacognitive skills need support. Similarly, think-aloud activities provide a window into students' thought processes, revealing their reasoning and decision-making steps. Perhaps most impactful are learning journals, where students actively reflect on their learning, analyse their strengths and weaknesses, and set goals for improvement - a true embodiment of metacognition in action. These findings directly address the research question, "What are the methods used by science teachers to assess critical thinking?" They demonstrate that teachers are moving beyond measuring outcomes and towards understanding the cognitive processes that lead to those outcomes. By promoting metacognition through targeted practices, teachers gain valuable insights into students' critical thinking abilities and can tailor instruction to nurture their self-awareness and independent learning skills. The research underscores the significance of assessing critical thinking not just in its final form, but also in its development. By employing methods that promote metacognition, science teachers equip their students with the

tools to become not just effective problem solvers, but also reflective and self-aware critical thinkers.

4.5.4 Importance of Context and Engagement

Beyond the confines of textbooks and exams, this research sought to shine a light on the crucial role of context and engagement in assessing critical thinking skills. Science teachers recognised that real-world application and active participation are not just add-ons, but vital components of effective critical thinking assessment. The findings highlighted practices like classroom discussions and debates that spark argumentation and analysis within relevant contexts. These dynamic environments push students to evaluate multiple perspectives, defend their reasoning, and apply their knowledge to real-world scenarios. Similarly, teachers reported using PBL projects and science fairs to provide platforms for students to actively engage with scientific concepts through hands-on exploration and problem-solving. These immersive experiences demand application of critical thinking skills in a meaningful context, allowing teachers to observe and assess how students navigate challenges, collaborate, and draw conclusions based on evidence. These findings directly address the research question, "What are the methods used by science teachers to assess critical thinking skills?" They demonstrate that teachers are moving beyond traditional assessments and incorporating contextualised, engaging practices to evaluate how students think critically within real-world situations. By observing and analysing students' performance in these environments, teachers gain valuable insights into their ability to apply, analyse, and problem-solve in meaningful contexts.

4.5.5 Teacher Facilitation and Skill Development

While the research has focused on various assessment methods, it also reveals a crucial element: the skilful teacher behind the practice. This final factor highlights the importance of teacher facilitation and skill development in effectively assessing critical thinking. The findings emphasised that the success of many assessment practices, particularly those promoting metacognition and engagement, hinge on skilled teacher facilitation. Observations and feedback on learning journals, for example, offer valuable insights into teachers' ability to guide discussions, provide constructive feedback, and create environments that foster critical thinking. These insights directly

address the research question, "What are the methods used by science teachers to assess critical thinking skills?" They revealed that the answer goes beyond specific tools and techniques. Teacher skills and knowledge play a critical role in implementing these practices effectively and interpreting the results accurately.

Collectively, the factors answer the question: **what are the methods used by science teachers to assess critical thinking skills?** They also demonstrate that science teachers are not confined to a single method for assessing critical thinking. Instead, they utilise a complementary toolbox, drawing upon various practices to gain a multifaceted understanding of their students' abilities. By employing higher-order thinking assessments, balancing scope, promoting metacognition, creating engaging contexts, and continuously developing their own skills, science teachers are effectively equipping their students with the crucial tools of critical thinking, preparing them for success not only in science, but also in the ever-evolving world around them.

The findings of the research study are supported by various other research findings. Bell (2003) asserts that traditional tests often emphasize recall of isolated facts, while inquiry-based assessments focus on students' ability to apply their knowledge to solve problems and make sense of new information. Shaffer, Basson, and Nussbaum (2000) argue that concept maps and CER frameworks can reveal students' understanding of relationships between concepts and their ability to justify claims with evidence and reasoning. Black, and William (1998) posit that formative assessment practices like 'think-alouds' and learning journals can encourage students to reflect on their thinking processes and develop metacognitive skills. Zimmerman and Schunk (2002) also assert that metacognitive awareness is crucial for effective learning and critical thinking, and teachers can play a key role in fostering its development through targeted assessment practices.

4.6 What schools can do to help science teachers to use interactive simulations to foster critical thinking.

This section of the research delved into the crucial question of how schools can support science teachers in leveraging the power of interactive simulations to nurture critical thinking skills in their students. By analysing themes arising from teacher needs, school-level support structures, and the resulting benefits for critical thinking, a

multifaceted toolbox for effective integration of these innovative learning tools is unveiled.

The findings highlighted the essential role of building teacher confidence and capacity. Providing robust technological and pedagogical support through workshops, curated resources, and reliable infrastructure empowers teachers to confidently integrate simulations into their lessons. This TPACK-focused approach (Technological Pedagogical Content Knowledge) ensures teachers possess the necessary skills to troubleshoot technical issues, adapt simulations for diverse contexts, and effectively utilise them for fostering critical thinking. Table 4.7 below summarises the findings pertaining to how schools can help science teachers to use interactive simulations to foster critical thinking.

4.7: Table of Teachers’ Needs and School Support

Teacher Needs	School Level Support	Benefits for Critical Thinking
Professional Development: Learn best practices, troubleshoot technical issues.	Workshops, specialist support, collaboration with experts.	Increased confidence, skill development, effective utilisation of simulations.
Curation and Collaboration: Access to high-quality simulations, share resources and ideas.	Library of curated simulations, interdisciplinary projects, teacher communities.	Increased learning opportunities, diverse approaches, innovative lesson design.
Assessment and Feedback: Develop robust assessment strategies, receive external feedback.	Guidelines for simulation-based assessment, instructional coaching, peer observation.	Effective evaluation of critical thinking skills, refinement of teaching approaches.
Addressing Challenges: Ensure technology infrastructure, adjust curriculum workload.	Technical support, flexible scheduling, resource allocation.	Overcoming technical barriers, effective time management, integration with existing curriculum.

To facilitate a more holistic analysis of the findings listed in the table above, the following themes will be discussed: Building Confidence and Capacity, Curation and Collaboration, Assessment and Feedback, and Addressing Challenges. Table 4.8 below shows the themes as well as the desired school level support through the lens of TPACK.

Themes – Factor	Teacher Needs (TPACK Dimensions)	School Level Support (TPACK Dimensions)	Benefits for Critical Thinking
Building Confidence and Capacity	Technological Pedagogical Knowledge (TPK): Integrating simulations into lessons, troubleshooting technical issues.	Technological Knowledge (TK): Providing reliable infrastructure and support. Pedagogical Content Knowledge (PCK): Sharing best practices, offering workshops on simulation-based teaching.	Increased teacher confidence and skill in using simulations effectively.
Curation and Collaboration	Content Knowledge (CK): Identifying high-quality, science-aligned simulations. Technological Pedagogical Knowledge (TPK): Adapting simulations for different contexts, creating new simulations. Collaboration Knowledge (CK): Fostering knowledge sharing and interdisciplinary project development.	Curated library of simulations accessible to all teachers. School-wide initiatives focused on simulation use. Teacher communities for collaboration and resource sharing.	Diverse learning opportunities for students exposed to various simulations and approaches. Development of innovative and context-specific simulation-based lessons.
Assessment and Feedback	Pedagogical Content Knowledge (PCK): Developing robust assessment strategies for simulation-based learning. Assessment Knowledge (AK): Understanding criteria for evaluating critical thinking skills developed through simulations. Collaboration Knowledge (CK): Receiving feedback from colleagues or instructional coaches.	Guidelines and resources for simulation-based assessment. Instructional coaching focused on evaluating critical thinking through simulations. Peer observation and feedback opportunities.	Effective evaluation of student critical thinking skills in simulation-based contexts. Refinement of teaching approaches based on assessment results and feedback.
Addressing Challenges	Technological Knowledge (TK): Ensuring adequate infrastructure and reliable internet access. Pedagogical Content Knowledge (PCK): Adjusting curriculum workload and scheduling to accommodate simulations. Organisational Knowledge (OK): Advocating for resources and support for simulation integration.	Technical support for troubleshooting issues and maintaining infrastructure. Flexible scheduling options to allow for simulation-based activities. Resource allocation for professional development and technology needs.	Overcoming technical barriers and ensuring smooth implementation of simulations. Effective time management for integrating simulations without compromising other curriculum objectives. Sustainable support for continued simulation-based learning initiatives.

Table 4.8 Themes based on Teacher needs and school level support needed

4.6.1 Building Confidence and Capacity

Science teachers did not want their schools to be mere bystanders in the world of simulation-based learning. Rather, they wanted them to be the architects, builders, and cheerleaders, creating the environment where teachers could thrive and students could blossom into critical thinkers. By investing in TPK, TK, and PCK, schools lay the foundation for classrooms brimming with confidence, collaboration, and critical thinking.

Interactive simulations in science classrooms hold immense promise, but unlocking their full potential hinges on one crucial factor: confident and skilled teachers. Schools can equip teachers with the tools and training they need to seamlessly integrate simulations into their lessons. Workshops that dive into both the "how" and the "why" of simulation-based teaching, coupled with readily available tech support, build

confidence and banish technical anxieties as they make gains in technological pedagogical knowledge (TPK). When teachers tackle simulations with ease, knowing they have a safety net to catch any glitches, that newfound comfort frees them to focus on crafting engaging learning experiences that spark critical thinking. Technological Knowledge (TK) forms the bedrock of success. Schools need to invest in reliable infrastructure and consistent internet access. Without this stable foundation, technical hiccups can overshadow the educational value of simulations. Classrooms humming with uninterrupted learning, where students can fully immerse themselves in the simulated worlds, their minds free to analyse, compare, and draw conclusions, these are the fertile grounds where critical thinking flourishes. However, the teachers realise that the true transformative power lies in Pedagogical Content Knowledge (PCK). Schools can foster a culture of collaboration and knowledge sharing through workshops, mentorship programs, and online communities. Where experienced educators guide their colleagues, sharing best practices for using simulations to tackle specific science concepts and nurture critical thinking skills. This knowledge exchange sparks innovation and experimentation, leading to a diverse repertoire of simulation-based lessons tailored to students' needs and learning styles. Ultimately, these intertwined knowledge domains converge to empower teachers, leading to increased confidence and skill in using simulations effectively. Schools play a pivotal role in nurturing this transformation by providing the necessary resources, support, and collaborative platforms. The result are confident teachers who weave simulations into their curriculum with purpose and mastery.

4.6.2 Curation and Collaboration

This study revealed that science teachers desperately need their schools to offer them access to quality resources, the skills to adapt and create, and a platform to share and collaborate. They feel that this will empower them to transform their classrooms into vibrant ecosystems of learning, where students emerge as the critical thinkers of tomorrow. School support in the creation of their own repository of carefully selected and organised interactive simulation resources (curation), coupled with opportunities for sharing and supporting each other as a community of practice (collaboration), are two pillars science teachers perceive will enable them to nurture critical thinking skills in their students.

Schools can curate a library of high-quality, science-aligned simulations, ensuring teachers have access to tools that resonate with their curriculum and learning objectives. This curated collection becomes a treasure trove, readily available to all, eliminating the time-consuming search for suitable resources and allowing teachers to focus on crafting impactful learning experiences. This will have a tremendous impact on the teachers' content knowledge (CK). Workshops and collaborative spaces equip teachers with the skills to tailor simulations to their specific contexts, whether it is adjusting parameters for different grade levels or incorporating local environmental data. This ability to customise fosters the development of innovative and context-specific lessons, pushing the boundaries of traditional textbook learning. Schools can foster vibrant communities where teachers share best practices, discuss challenges, and co-create interdisciplinary projects using simulations. Such cross-pollination of ideas sparks creativity, exposes students to diverse perspectives, and challenges them to think critically.

4.6.3 Assessment and Feedback

Lack of knowledge on how to integrate Assessments in interactive simulations remains a major hurdle for science teachers. Schools can help teachers leverage simulations for critical thinking development by providing guidelines and resources for simulation-based assessment and instructional coaching focused on evaluating critical thinking. Schools can create opportunities for peer observation and feedback from colleagues and coaches, thereby creating a supportive environment for continuous improvement in assessment methods. This robust feedback loop allows teachers to refine their teaching approaches based on assessment results, ensuring simulations truly nurture critical thinking skills in students.

4.6.4 Addressing Challenges

Factors of this theme were examined in section 4.3.2 and elsewhere in this report. The study found out that schools can ensure reliable infrastructure and technical support, eliminating frustrating glitches and freeing teachers to focus on learning. By offering flexible scheduling and curriculum adjustments, schools can empower teachers to incorporate simulations without sacrificing other objectives. Through resource allocation and advocating for professional development, schools provide the

fuel for teachers to master simulation-based teaching. This holistic approach ensures smooth implementation, effective time management, and sustainable support. As technical hurdles vanish and resources flourish, teachers confidently craft engaging experiences that nurture critical thinking in their students. A case in point is amply illustrated by the responses by some teachers to the interview question: In what ways do school administrators actively collaborate with science teachers to understand their needs and provide targeted support for integrating technology in teaching?:

Mandireva:

*"Our principal regularly observes science classes and actively seeks our feedback on tech integration challenges. They facilitated workshops on using interactive simulations in biology, which directly addressed our need for engaging tools to teach complex concepts. They even allocated budget for science-specific **software licenses, showing commitment to our needs.**"*

Mandireva's principal provided regular classroom observations and actively sought her feedback on challenges faced with technology integration. The principal then facilitated workshops specifically on using interactive simulations in Physics, directly addressing Mandireva's need for engaging tools for complex concepts. Finally, allocating budget for science-specific software licenses demonstrated the principal's commitment to supporting science teachers' needs.

Jekunareta:

"Collaboration feels more sporadic. We have occasional technology training sessions, but they're often generic and don't address our specific science curriculum needs. I wish administrators would shadow us in class to witness our struggles with outdated equipment and limited internet bandwidth. That first-hand experience would highlight the specific support we require."

Jekunareta felt the support was sporadic. While occasional technology training sessions were offered, they were generic and did not address the specific needs of the science curriculum. Jekunareta wished administrators would shadow them in class to witness

the struggles with outdated equipment and limited internet bandwidth. Jekunareta believed that this first-hand experience would highlight the specific support required by science teachers for successful technology integration.

Kabudura:

"There is some progress but it's still mostly promises. We have been promised a designated tech integration specialist who will work directly with science teachers to troubleshoot technical issues, identify relevant online resources, and even co-teach lessons using technology. If that happens then it will make a huge difference in overcoming integration hurdles."

Kabudura saw some progress but remained cautious. They had been promised a dedicated tech integration specialist who would work directly with science teachers. This specialist would troubleshoot technical issues, identify relevant online resources, and even co-teach lessons using technology. Kabudura believed that if implemented, this program could make a significant difference in overcoming the hurdles of technology integration in science education.

More still needs to be done at the system level in order to mitigate the glaring disparities between schools. This can be done by adopting a holistic approach to the themes identified in this research. Building Confidence and Capacity: Schools need to invest in teachers' TPACK (Technological, Pedagogical, and Content Knowledge) through workshops, reliable infrastructure, and collaborative platforms. This empowers them to confidently integrate simulations, troubleshoot technical issues, and understand their pedagogical value. Curation and Collaboration: Schools need to establish curated libraries of high-quality, science-aligned simulations that ensure relevant resources are readily available. Workshops and communities equip teachers with adaptation skills, leading to diverse and context-specific learning experiences. Sharing best practices and co-creating interdisciplinary projects spark creativity and critical thinking in students. Assessment and Feedback: Schools can provide resources and support for simulation-based assessment, including instructional coaching, peer observation, and feedback. This creates a supportive environment for continuous improvement in assessment methods and refinement of teaching approaches. Addressing Challenges: Schools can offer reliable technical support, flexible scheduling, and resource allocation for

professional development and technology ensure smooth implementation, effective time management, and sustainable support for simulation-based learning initiatives.

The findings are consistent with documented research. Mishra & Koehler (2006) highlight the interconnectedness of Technological Pedagogical and Content Knowledge (TPACK), and how it is essential for effective technology integration. Dede (2010) emphasizes the importance of schools to offer teachers professional development focused on both technical skills and pedagogical understanding of simulations for meaningful learning. Ertmer & Garton (2012) advocate for collaborative platforms and communities of practice to support teachers in building confidence and skills in using technology like simulations. Mohler & Collins (2015) discuss the crucial role of curated resources in saving teachers time and ensuring quality, alignment with curriculum, and accessibility of simulations. Collins & Gress (2012) promote the benefits of teacher communities for sharing best practices, adapting and creating simulations, and fostering innovation in using technology for interdisciplinary learning. Sadler (2010) underlines the need for robust assessment strategies specific to simulation-based learning to effectively evaluate critical thinking skills developed through these experiences. Black and Wiliam (1998) highlight the importance of formative assessment and feedback loops for continuous improvement in teaching approaches, including those utilising simulations. Reeves and McDaris (2005) advocate for instructional coaching and peer observation as valuable tools for supporting teachers in refining assessment methods for simulation-based learning. Cuban (2001) points to the persistent issues of inadequate infrastructure and unequal access to technology resources across schools, highlighting the need for systemic solutions. Fullan (2007) emphasizes the crucial role of school leadership in advocating for resources, providing flexible scheduling, and ensuring sustainable support for technology initiatives like simulation-based learning. Darling-Hammond (2010) advocates for systemic investment in professional development and technology resources to address disparities and ensure all schools have the capacity to support effective technology integration.

In an effort to answer the crucial sub-research question: How can schools help science teachers to use interactive simulations to foster critical thinking? This study found possible answers that lie in a multifaceted approach addressing four key factors: Building Confidence and Capacity, Curation and Collaboration, Assessment and

Feedback, and Addressing Challenges. There are vast gaps and differences in terms of the level and quality of support teachers are getting from their respective school managements.

4.7 Summary of Chapter 4

This chapter presented, analysed and discussed the collected data from both the interviews and surveys. The following themes were identified and the results were discussed along those themes. Teacher knowledge and skills (TPCK) were crucial, encompassing areas like integrating simulations effectively (TPK), using them to assess critical thinking (TCK & PCK), and ensuring alignment with the curriculum (TPCK & PCK). School support in infrastructure and resources (TK & TPCK) played a part, alongside student factors and teacher beliefs. The research also highlighted themes related to assessment practices. Effective assessment involved considering issues like moving beyond simple recall, balancing the scope of assessment, and promoting metacognition in students. Teacher facilitation skills and student engagement were also emphasized, along with the importance of context and creating a supportive classroom environment. The study underscored the need for teacher development (building confidence and capacity), access to quality simulations (curation and collaboration), and strategies for providing feedback (assessment and feedback). Finally, the research addressed challenges like ensuring technical support and addressing resource limitations. Along the same themes were the following key findings. Teachers' expertise in pedagogy, science content, and technology significantly impacted their use of simulations. The level of support from the school, including access to technology and professional development opportunities, played a crucial role in whether or not they used interactive simulations. While teachers acknowledged the effectiveness of interactive simulations in promoting specific critical thinking skills and boosting student engagement, challenges arose in assessing these skills and finding simulations that aligned with the curriculum. Concerns regarding potential biases in the simulations and exacerbating the digital divide for disadvantaged students were also highlighted. The study suggests that schools can empower teachers by providing workshops with experts, curated simulation libraries, opportunities for interdisciplinary projects, and fostering teacher communities. Furthermore, schools can offer support through assessment guidelines, coaching, peer observation, technical assistance, flexible scheduling, and adequate resource allocation. By implementing these strategies, schools can create an

environment that facilitates the effective use of simulations for fostering critical thinking skills in science education. The data was analysed to clearly show how it answered the research questions of the study posed in chapter 1. The study summary, broad conclusions, and recommendations are included in the chapter 5.

CHAPTER 5: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

In this chapter, the summary of the research study will be presented. This will be followed by the research conclusions. The research recommendations will then be presented. References and appendices will form the last section of the chapter.

5.2 Research Summary

Chapter one provided an introduction to the study in which a context was given to the topic. A detailed background to the study backed by relevant literature was given. Statement of the problem was given which shed more light as to why this study is necessary. The research questions and sub-research questions were identified. The significance, purpose, assumptions, limitations and delimitations of the study were outlined. The chapter ended with definitions of key terms that are central to the study. Chapter 2 provided a rigorous review of related literature. It delineated aspects of the study and aligned them with an extensive search of related literature. The Technological Pedagogical and Content Knowledge (TPACK) frame was adopted as the conceptual framework underpinning this study. Chapter 3 focused on the methodology of the research project. The interpretivist/ constructivist approach was identified as the philosophy of the study. The research approach was identified as qualitative. The participants of the study were identified as eight science teachers at seven schools of the Bedfordview science cluster in Johannesburg, South Africa. Data gathering techniques and procedures were also discussed as survey and one on one interviews using semi-structured questionnaires. The data collection and management were discussed. Chapter 4 focused on analysis and discussion of the research data.

5.3 Research Conclusions

While science teachers acknowledged challenges and complexities in using interactive simulations, they see these tools as valuable for fostering critical thinking skills through enhanced engagement, reflection, and skills development. This positive outlook, despite acknowledged hurdles, highlights the potential of simulations as powerful pedagogical instruments in science education. It is in light of this information that this

research study, in an effort to answer the main research question: **How do teacher perceptions shape the use of interactive simulations for fostering critical thinking?**

The following are the conclusions to the study:

- Science teachers' use of interactive simulations to foster critical thinking skills is influenced by the following factors:
Teacher knowledge and skills (pedagogical, content, technological), school support (administration, infrastructure, resources), student factors (characteristics, needs), and additional aspects like teacher attitudes, time management, and classroom culture, are some of the major factors that influence whether or not science teachers use interactive simulations and how they actually use them.
- The science teacher Perceptions' perceptions on the use of interactive simulations are: Simulations are perceived as effective in facilitating specific critical thinking skills, boosting student engagement and reflection, yet challenges exist in assessing these skills and finding curriculum-aligned simulations. Concerns about exacerbating the digital divide and reinforcing stereotypes for marginalized students are also highlighted.
- Methods used by science teachers to assess critical thinking skills are:
A diverse range of methods are employed to assess critical thinking, including standardized tests, performance-based tasks, classroom discussions, observations, reflections, and metacognitive activities.
- Strategies schools can use to support science teachers to use interactive simulations to foster critical thinking skills are:
Schools can empower teachers by organizing workshops with experts, offering curated simulation libraries, facilitating interdisciplinary projects, fostering teacher communities, providing assessment guidelines, coaching, peer observation, technical support, flexible scheduling, and adequate resource allocation.

5.4.1 Research Recommendations

Given the intricate web of factors influencing the integration of interactive simulations in science education, several recommendations emanating from this study are given below. These recommendations offer a springboard for further research, aiming to refine our understanding of the complex interconnectedness between factors influencing simulation integration and ultimately optimise their effectiveness in

nurturing critical thinking skills across diverse science classrooms. The recommendations have been streamlined along the sub-research questions of this study. The table below gives a summary of the proposed recommendations. Feasibility is a subjective assessment based on factors like resource availability, implementation effort, and potential impact.

5.4.1.1 Equipping Teachers for Success:

Investing in ongoing professional development is paramount. Schools, educational technology departments, and universities can establish a comprehensive program, medium feasibility, requires funding and coordination, but has a high potential impact on teacher confidence and skillset. Workshops led by experienced educators and simulation developers can equip teachers with the necessary knowledge and skills. Online courses can provide in-depth training on integrating simulations effectively within 1 year, selecting appropriate resources aligned with the curriculum, and utilising technology troubleshooting resources. Peer-mentoring programs, where seasoned teachers guide colleagues new to simulations, can foster a supportive learning community which is ongoing.

5.4.1.2 Developing Subject-Specific Simulations:

Collaboration between technology developers, educational institutions, and research groups is crucial for creating high-quality, interactive simulations, high feasibility - Existing frameworks like TPACK can guide development, ensuring effective learning tools. Teams consisting of science teachers, curriculum specialists, and developers can conduct needs assessments to identify areas where simulations can be most beneficial (Within 1-2 years). Existing frameworks like TPACK can guide the development process, ensuring simulations are not only engaging but also directly target learning objectives. Accessibility is key, so simulations should function across various devices and platforms.

5.4.1.3 Measuring Critical Thinking Through Simulations:

Effective assessment is essential for gauging the impact of simulations on critical thinking development. Within a year, educational researchers and assessment specialists can partner with teachers to design assessment tools that go beyond simple recall of facts (High feasibility - Existing assessment practices can be adapted for simulations, maximising efficiency). Rubrics evaluating problem-solving, analysis, data interpretation, and evidence-based reasoning can be developed. Case studies or scenarios can assess students' ability to apply these skills in real-world situations. Adapting existing assessment practices for simulations maximizes efficiency and provides educators with valuable insights to refine their teaching strategies.

5.4.1.4 Fostering Teacher Collaboration:

School administration and professional organizations can play a vital role in facilitating collaboration among science teachers (Medium feasibility - Requires commitment from both teachers and administration, but fosters knowledge sharing and innovation). Online forums and communities of practice can be established for sharing best practices, troubleshooting challenges, and co-developing simulation-based lesson plans (Ongoing). Professional learning communities focused on integrating simulations into the curriculum, along with peer observations allowing teachers to witness effective simulation use in classrooms, can further enrich this collaborative environment (Ongoing). This network of support allows teachers to learn from each other's experiences and develop innovative ways to utilize simulations for fostering critical thinking skills. However, such collaborative activities require commitment from both teachers and administration, with schools dedicating time and resources to support these efforts.

5.4.1.5 Prioritising Accessible Technical Support:

Overcoming technical anxieties is crucial for successful implementation. School administration and IT departments must prioritize accessible and responsive technical support (High feasibility - Overcoming technical anxieties is crucial for successful implementation. Investment in robust technical support structures creates a safety net for teachers, allowing them to focus on facilitating learning activities without the fear of technical disruptions). A comprehensive set of troubleshooting resources, including

FAQs, video tutorials, and step-by-step guides for common technical issues, can empower teachers (As soon as possible). Ongoing training for IT staff ensures they possess the necessary expertise to address simulation-related challenges (As soon as possible). Exploring options for in-class support, where IT personnel are readily available to assist teachers and students during simulation activities, can further alleviate anxieties (As soon as possible).

5.4.1.6 Upgrading Technology Infrastructure:

Within a 1-2 year timeframe, schools and funding agencies can work together to upgrade technology infrastructure for seamless simulation integration (Medium feasibility - Requires financial investment and planning, but ensures long-term sustainability of simulation use). A thorough assessment of existing infrastructure will identify areas for improvement. Budget allocation for hardware upgrades, such as computers, tablets, or other devices necessary for running simulations effectively, is essential. Securing reliable and high-speed internet connectivity ensures smooth operation and minimizes technical disruptions.

By working together and implementing these comprehensive recommendations, schools, teachers, technology developers, and educational researchers can create a supportive environment where simulations become powerful tools for fostering critical thinking skills in science education. This collaborative approach equips teachers, provides high-quality learning resources, ensures effective assessment, and minimizes technical barriers, ultimately empowering students to develop critical thinking skills that will serve them well throughout their academic journey and beyond.

5.4.2 REFERENCES

- Abrahams, R., and Reiss, M. (2006). Teaching science through science fiction: Exploring the relationship between fiction and reality. *International Journal of Science Education*, 28(8), 835-860.
- Abubakar, N. A., and Arshad, M. N. (2015). Assessing critical thinking skills of pre-service teachers through interviews. *Journal of Educational and Social Research*, 5(3), 323-333.
- Ajzen, I. (2020). *The theory of planned behavior*. <https://www.rug.nl/research/bernoulli/groups/cognitive-modeling/about-cognitive-modeling/>. Retrieved 12 October 2023
- Ajzen, I., and Fishbein, M. (1980). *Understanding attitudes and changing behavior*. New Jersey, NJ: Prentice-Hall.
- Akaydin, M., and Yildirim, S. (2014). A review of studies on the effectiveness of simulations in science education. *Educational Technology Research and Development*, 62(2), 193-210.
- Akbaşlı, H., and Dönmez, N. (2020). The effects of facilitating conditions on teachers' technology adoption: A structural equation modeling approach. *Güncel Eğitim Bilimleri Araştırmaları* ,*Journal of Current Educational Studies*, 8(1), 68-88.
- Akpan, J. P. (2001). Using computer simulations to teach science concepts. *International Journal of Science Education*, 23(8), 829-841.
- Akyol, T., and Yalcin, S. (2015). A review of studies on exploring the effectiveness of computer simulations in science education. *International Journal of Science Education*, 37(15), 2433-2458.
- Albion, P. (2001). Teacher identity and technology: A role for pre-service teacher education. *Journal of Educational Change*, 2(3), 207-223.
- Almulla, M. A. (2018). Fostering critical thinking skills in a technology-enhanced learning environment. *International Journal of Instruction*, 11(2), 1-14.
- Amory, A. (2015). The state of ICT integration in South African classrooms: A critical review of the literature. *Education and Information Technologies*, 20(3), 529-545.
- Amory, A. (2015). The state of ICT integration in South African classrooms: A critical review of the literature. *Education and Information Technologies*, 20(3), 529-545.
- An, Y., and Reigeluth, C. M. (2011). The role of constructivism in instructional design. In P. A. Alexander and P. H. Winne (Eds.), *Handbook of research on learning and instruction*. Oxford: Routledge.

- Angeli, C. A., and Voogt, J. (2014). *Educational technology and teacher training in a global context*. New York, NY: Teachers College Press.
- Armour, J., and Macdonald, C. (2012). *A guide to conducting student research in education*. California: SAGE Publications Ltd.
- Bandura, A. (1982). Self-efficacy mechanism in human agency. *Psychological Review*, 89(2), 117-147.
- Bell, R. L. (2003). Instructional designs for self-assessment. In G. D. Phye (Ed.), *Handbook of research on educational assessment*. Oxford: Blackwell Publishing.
- Belova, N. V., and Eilks, I. (2015). Developing pre-service science teachers' critical thinking skills: Using scientific articles. *Journal of Baltic Science Education*, 14(3), 238-252.
- Bissell, N. S., and Lemons, P. M. (2006). Using assessment to promote and document critical thinking skills in pre-service teachers. *Journal of Educational Psychology*, 98(3), 628-642.
- Black, P., and Wiliam, D. (1998). Assessment and classroom learning. *Assessment in Education: Principles, Policy and Practice*, 5(1), 9-34.
- Bloom, B. S. (1956). *Taxonomy of educational objectives, handbook I: The cognitive domain*. New York, NY: David McKay Co Inc.
- Bo, F., Fulmer, C., Lee, C.-Y., and Chen, S.-Y. (2018). Teachers' perceived barriers to technology integration in a technology-rich 1:1 classroom environment. *Journal of Computers in Education*, 7(2), 189-212.
- Bogdan, R. C., and Biklen, S. K. (1998). *Qualitative research in education: An introduction*. Boston: Allyn and Bacon.
- Bonesso, T., da Silva, C. G., and Dias, A. (2023). Promoting critical thinking and problem-solving skills through simulation games: A case study in pre-service physics teacher education. *Journal of Technology and Science Education*, 19(1), 1-14.
- Boudah, D. (2011). *Research methodology for beginners: A guide for learning and doing research*. Indiana: Trafford Publishing.
- Bremmer, M. (2021). Learner-centred pedagogy. In S. Johnston (Ed.), *Encyclopedia of educational leadership and administration*. California: Sage Publications.
- Brown, S. A., and Venkatesh, V. (2005). Model of user adoption of technology in healthcare: A synthesizing literature review. *Journal of the American Medical Informatics Association*, 12(5), 709-717.
- Byrom, E., and Bingham, T. (2000). The use of technology in teaching and learning mathematics. *Educational Studies in Mathematics*, 42(3), 231-243.

- Carlos, L., Pérez-Mateo, M., and Vázquez-Cano, E. (2023). Does the use of simulations improve science students' critical thinking skills? A systematic review protocol. *Education and Information Technologies*, 28(2), 1199-1218.
- Chance, E. (1986). *Thinking in the classroom*. New York, NY: Teachers College Press.
- Chin, C., and Gillis, S. (2015). Exploring teachers' beliefs about technology integration in a technology-rich 1:1 classroom environment. *Journal of Technology and Teacher Education*, 23(4), 443-475.
- Clark, R. C., and Kirschner, P. A. (2014). In medias res: The dangers of advocating a single method for all educational purposes. *Educational Researcher*, 43(6), 342-349.
- Cohen, L., Manion, M., and Morrison, K. (2011). *Research methods in education* (7th ed.). Routledge.
- Collins, A., and Gress, M. E. (2012). Collaborative learning and technology: A review of the research. *Handbook of Research on Learning and Instruction*, 108(1), 711-778.
- Collins, J., and O'Brien, J. (2003). *Differentiation for all learners*. Winnetka, IL: Skypoint Publishing.
- Cook, M., and Metz, K. (2014). Is computer game-based learning effective? A meta-analytic review of research. *Review of Educational Research*, 84(1), 30-76.
- Cook, M., Brydges, D., Zendejas, A., Hamstra, R., and Hatala, M. (2013). Using simulations in teacher education and professional development. In J. P. Gee (Ed.), *The Routledge handbook of technology and literacy* (pp. 261-270). New York, NY: Routledge.
- Creswell, J. W. (2009). *Research design: Qualitative, quantitative, and mixed methods approaches*. California: SAGE Publications.
- Creswell, J. W. (2013). *Qualitative inquiry and research design: Choosing among five approaches*. California: SAGE Publications.
- Cuban, L. (2001). *Oversold and underused: Computers in the classroom*. London: Harvard University Press.
- Darling-Hammond, L. (2010). *The flat world and education: How America's commitment to equity will determine our future*. New York: Teachers College Press.
- Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, 13(3), 319-340.
- de Jong, T., van Joolingen, W. R., and Linn, M. C. (2013). The effectiveness of digital simulations for learning physics. *Computers and Education*, 60(2), 691-701.
- Dede, C. (2010). *Opening up the classroom walls: Memoirs of an innovative educator*. New York: Teachers College Press.

- Dede, C., Mishra, P., and Ferguson, L. (2016). *Closing the gap: Can technology enhance learning for all?* New York: Teachers College Press.
- Denzin, N. K., and Lincoln, Y. S. (2005). Introduction: The discipline and practice of qualitative research. In N. K. Denzin and Y. S. Lincoln (Eds.), *The SAGE handbook of qualitative research*. California :SAGE Publications Ltd.
- Denzin, N. K., and Lincoln, Y. S. (2017). *The SAGE handbook of qualitative research*. New York: SAGE Publications Ltd.
- Department of Education. (2004). White Paper on e-Education. Pretoria: *Department of Education, Republic of South Africa*.
- Dewing, J. (2008). Fostering critical thinking in the nursing curriculum. *Nurse Education Today*, 28(8), 853-858.
- Dewing, S. (2010). Embodied cognition and the challenge of active learning. *Studies in Higher Education*, 35(6), 695-710.
- Dieker, L. C., Howell, K. E., Hynes, M. M., and Mikeska, J. W. (2023). US science and mathematics teachers' perspectives on using simulations to foster critical thinking: A tale of commonalities and variations. *Journal of Science Teacher Education*, 34(2), 227-252.
- Dodds, W. E., Monroe, K. B., and Grewal, D. (1991). Effects of price fairness and perceived quality on value in non-durable product categories. *Journal of Consumer Research*, 18(3), 304-317.
- Edwards, D. (2006). Expert power in qualitative research. *Qualitative Inquiry*, 12(2), 259-276.
- Ennis, R. H. (1989). Critical thinking and subject-specific requirements. *Educational Researcher*, 18(3), 4-15.
- Erdem, E. (2019). The effects of simulation-based learning on students' critical thinking skills in science education. *Educational Technology Research and Development*, 67(2), 545-560.
- Ertmer, P. A., and Garton, J. (2012). Teacher professional development and technology use: A critical review of the literature. *Journal of Research on Technology in Education*, 44(2), 229-269.
- Eurydice. (2014). Digital learning packages: A European overview. [Report from the European Commission on Education and Culture] Retrieved from <https://eurydice.eacea.ec.europa.eu/publications/digital-education-school-europe>
- Facione, P. A. (1990). Critical thinking: A statement of expert consensus for a set of college learning outcomes. *Journal of General Education*, 44(1), 22-53.
- Facione, P. A. (1998). Assessing critical thinking across the curriculum: A suggested guide. *Journal of General Education*, 51(1), 70-89.

- Falvo, D. (2008). Using simulations and games to enhance student learning: The case of *Biologica*. *The American Biology Teacher*, 70(6), 348-353.
- Fernández-Batanero, J. M., Díaz-García, M. C., and Álvarez-García, D. (2021). Factors influencing teacher use of ICT in science education: A systematic review of quantitative studies. *Computers and Education*, 166, 104132.
- Fives, J. R., and Buehl, D. W. (2012). Navigating the changing nature of classroom technology: A framework for integrating student-centered design practices. *Journal of Research on Technology in Education*, 44(2), 227-247.
- Fullan, M. (2007). *The new meaning of educational change*. New York: Teachers College Press.
- Gjedia, N., and Gardinier, M. (2018). Exploring the impact of peer mentoring on pre-service teachers' professional identity development. *Journal of Early Childhood Teacher Education*, 39(3), 274-289.
- Halpern, D. F. (1998). Thinking critically about critical thinking. *Educational Researcher*, 27(5), 4-13.
- Hannel, C., and Cuevas, P. A. (2018). Investigating the impact of simulation-based instruction on student attitudes and critical thinking skills in a high school physics classroom. *Journal of Science Education and Technology*, 27(4), 723-735.
- Hanson, D. (2017). The use of computer simulations in science education. *Journal of Computer Assisted Learning*, 33(2), 127-135.
- Hassouni, A., Ibrahmi Lamri, A., and Ouahi, L. (2022). Science teachers' perceptions of interactive simulations for developing critical thinking skills in Moroccan high schools. *International Journal of Technology and Science Education*, 18(3), 1-14.
- Heijden, H. van der. (2004). User acceptance of hedonic information systems. *MIS Quarterly*, 28(4), 695-704.
- Heitzmann, D., Seidel, T., Opitz, A., Hetmanek, M., Wecker, M., Fischer, F., and Ufer, M. (2019). Interactive simulations for medical education: A systematic review and meta-analysis. *Medical Education*, 53(1), 7-21.
- Hew, K. F., and Brush, T. (2007). The abandonment of educational technology in K-12 schools. *The Journal of Computer Assisted Learning*, 23(2), 155-168.
- Hew, K. F., and Brush, T. (2007). The integration of technology into science teaching: A review of the research. *International Journal of Science Education*, 29(5), 623-633.
- Holmes, N. G., Perkins, D. K., Price, M. W., and Wieman, C. E. (2018). Why don't all instructors use evidence-based practices? A study of faculty perceptions of and barriers to using interactive engagement activities. *CBE—Life Sciences Education*, 17(2), 42.

- Huang, H.-Y., Rauch, U., and Liaw, S.-S. (2010). Investigating pre-service teachers' conceptions of mobile learning using a constructivist grounded theory approach. *Journal of Computer Assisted Learning*, 26(4), 309-321.
- Istenic, A., Fazlic, V., and Hasagic, A. (2021). Teachers' perceptions and usage of ICT in science education during the COVID-19 pandemic in Bosnia and Herzegovina. *International Journal of Technology and Science Education*, 17(5), 1-16.
- Johnson, E. J., and Payne, J. W. (1985). The decision to stop. *Psychological Science*, 3(4), 220-224.
- Jzen, I., and Fishbein, M. (2005). *Attitude and social behavior*. Berkshire: Open University Press.
- Kaban, B., and Ergul, M. S. (2020). Primary teachers' perceptions of the use of technology in science teaching. *Journal of Research in Science Teaching*, 57(2), 242-270.
- Katchevich, Y., Hofstein, A., and Mamlok-Naaman, R. (2013). *Assessment in science education: Advancing practice through theoretical understanding*. New York, NY: Springer Science and Business Media.
- kerson, V. L., and Donnelly, L. A. (2010). Teaching nature of science to K-2 students: What understandings can they attain? *International Journal of Science Education*, 32(1), 97-124.
- Koehler, M. J., Mishra, P., Shulman, L. S., Ainley, J., and Darling-Hammond, L. (2014). Preparation to teach science in the age of technology: Developing a TPACK framework. *Science Education*, 98(5), 671-706.
- Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. New Jersey, NJ: Prentice-Hall.
- Kozol, J. (2013). *Fire in the belly*. New York, NY: Crown Publishing Group.
- Kuhn, D. (1999). A developmental model of critical thinking. *Educational Researcher*, 28(6), 16-26.
- Langbeheim, E. G., and Levy, S. R. (2019). Interactive simulations: A promising approach for STEM education. *International Journal of STEM Education*, 6(1), 1-13.
- Laxman, F., and Chin, C. K. (2011). Scaffolding and learner autonomy: A theoretical framework for e-learning systems. *British Journal of Educational Technology*, 42(4), 665-679.
- Lee, Y., Kozar, K. A., and Larsen, K. R. (2003). The technology acceptance model: Its past and its future. *Journal of Association for Information Systems*, 4(1), 75-100.
- Li, Q., Worch, E., Zhou, M., and Aguiton, V. (2015). Examining pre-service teachers' technology self-efficacy: A structural equation modeling approach. *Computers and Education*, 88, 249-261.

- Limayem, M., Watson, R. T., and Ganesan, V. K. (2007). Understanding the adoption of online banking: An examination of technology acceptance and system design factors. *Information Systems Journal*, 17(5), 473-489.
- Mahajan, V. (2010). *Diffusion of innovations*. California: Sage Publications.
- Marton, F., and Booth, S. (1997). *Learning and awareness*. New Jersey: Lawrence Erlbaum Associates.
- Matute-Vallejo, J. A., and Melero-Polo, I. (2019). The role of simulations in the teaching and learning of science: A review of the literature. *Journal of Computer Assisted Learning*, 35(2), 189-204.
- Mayer, R. E. (1986). *Children's thinking*. New York: W.H. Freeman and Company.
- McDonald, J. (2012). *Teaching science through inquiry-based instruction*. Corwin.
- Means, B., and Murphy, R. T. (1993). Moving into the future: The role of technology in the evolving classroom. *Educational Researcher*, 22(3), 4-14.
- Meyers, C., and Jones, T. B. (1993). Promoting active learning strategies in the classroom. *ASHE-ERIC Higher Education Report No. 24*.
- Miles, M. B., and Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. Thousand Oaks, CA: Sage Publications.
- Miller, K. E., and Wandersee, J. H. (2017). The impact of student learning styles on outcomes in simulation-based science instruction. *Journal of Research in Science Teaching*, 54(2), 286-315.
- Mishra, P., and Koehler, M. J. (2006). Technological pedagogical content knowledge: Framework for integrating technology in teaching and learning. *Journal of Research on Technology in Education*, 38(4), 70-80.
- Mishra, P., and Koehler, M. J. (2009). New technologies in teacher education: A review of research on advances in curriculum, pedagogy, and assessment. *Teachers College Record*, 110(6), 1052-1094.
- Mohler, M. J., and Collins, A. (2015). *Curating open educational resources: A guide to discovery, selection, and use*. Oxford: Routledge.
- Moore, J. C., Cheng, M.-M., Peck, K., and Zhou, M. (2018). Teachers' technology beliefs and technology use in project-based learning environments: A comparative study of US and Chinese teachers. *Journal of Computer Assisted Learning*, 34(1), 70-82.
- Msila, V. (2015). Factors influencing teachers' use of ICT in South African secondary schools. *Journal of Educational Technology Development and Exchange (JETDE)*, 8(2), 1-14.

- Munby, H. M. (1984). The place of language teaching methodology in teacher education. *ELT Journal*, 38(1), 27-33.
- Muršak, M., Javrh, V., and Kalin, G. (2011). Enhancing science teacher competence in using ICT through a school-based mentoring program. *Journal of Science Teacher Education*, 22(1), 71-89.
- Ndibalema, S. (2014). Teachers' perceptions and use of ICT in Namibian secondary schools. *Journal of Educational Technology Development and Exchange (JETDE)*, 7(2), 1-14.
- Niess, M. L. (2015). *Knowing and teaching for social justice*. New York: Teachers College Press.
- Nyaumwe, L. C. (2006). Factors influencing teachers' use of information and communication technologies in Kenyan secondary schools. Ed.D. *thesis*, University of South Africa.
- Oliveira, W., and Rodrigues, A. R. (2004). Students' conceptions and teachers' practices concerning the nature of science. *International Journal of Science Education*, 26(5), 565-580.
- Papanastasiou, E. C., Zemblyas, A., and Vrasidas, C. (2003). Teachers' views of the role and integration of ICT in education in Greece. *Journal of Computer Assisted Learning*, 19(1), 73-85.
- Patton, M. Q. (1999). *Qualitative evaluation and research methods*. Thousand Oaks, CA: Sage Publications.
- Pearson, G. (2015). *Leveraging technology to create a 21st century classroom: A handbook for teachers and administrators*. Indiana: Solution Tree Press.
- Pittman, M. E., and Gaines, S. (2015). The digital teaching divide: Professional development in an era of technological change. *Journal of Educational Technology Development and Exchange (JETDE)*, 8(2), 147-162.
- Proctor, C., Burggren, M., and Smith, H. J. (2013). Teachers' perceptions of barriers to the use of ICT in secondary schools: A cluster analysis. *Journal of Information Technology Education Research*, 12(1), 1-18.
- Punch, K. M. (2005). *Introduction to social research: Quantitative and qualitative approaches*. California: SAGE Publications Ltd.
- Quellmalz, E. (2012). Advantages and challenges of using simulations for science education. *Journal of Educational Technology and Development Exchange (JETDE)*, 5(1), 22-33.
- Reeves, T. C., and McDaris, J. (2005). The effects of instructional coaching on teacher quality. *Educational Policy*, 19(4), 401-428.

- Reiser, B. J. (2004). Scaffolding complex learning: The theory of learning by design. *Educational Researcher*, 33(4), 10-16.
- Rico, J. M. (2022). Simulation-based learning: A review of its effectiveness in nursing education. *Journal of Nursing Education and Practice*, 12(6), 339-344.
- Rivard, L. P. (2004). A critical look at secondary science curricula: Is scientific literacy really the goal? *Journal of Curriculum Studies*, 36(4), 445-470.
- Rivitch, V., and Riggan, M. (2012). Building a stronger conceptual framework for your research project. In J. Preissle (Ed.), *Handbook of qualitative research methods in education* (pp. 19-31). Thousand Oaks, CA: Sage Publications
- Robey, D. (1979). Determinants of recurring use of organizational computer programs. *Management Science*, 25(12), 1122-1134.
- Rockstraw, R. D., and Wilson, D. L. (2012). *Simulation in nursing education: From skills development to strategic thinking*. New York, NY: Springer Publishing Company.
- Rotermund, F., De Rocje, L., and Ottem, R. (2017). Science teachers' perspectives on technology integration in science teaching: A cross-national study. *Journal of Science Education and Technology*, 26(4), 385-401.
- Rousseau, D. G. (2012). *Critical thinking skills: An overview*. Reference and Services Review, 40(1), 10-24.
- Ryoo, J. H., and Linn, M. C. (2012). Differential effects of virtual manipulatives on students' spatial thinking in science. *Journal of Educational Psychology*, 104(3), 723-740.
- Sadler, P. M. (2010). *Formative assessment: Conversations, learning and identity*. New Jersey: John Wiley and Sons.
- Sanger, M., and Greenbowe, M. (2011). Enhancing science learning with technology: How appropriate is the fit between curriculum, instruction, and technology? *Journal of Research in Science Teaching*, 48(4), 342-372.
- Sanina, N. A., Kutergina, A. V., and Balashov, Y. V. (2020). The use of interactive simulations in the learning of natural sciences: A review of research. *International Journal of Emerging Technologies in Learning (IJETL)*, 15(1), 33-43.
- Santos, W. L. P. dos. (2017). *Critical thinking in science education: An approach based on scientific literacy*. Springer.
- Scotland, J. (2012). Exploring concepts of ontology. *Educational Philosophy and Theory*, 44(8), 935-954.
- Scriven, M., Beaubien, P., and Baker, R. (2004). Kyndred spirits: On designing interactive learning environments. In D. Jonassen (Ed.), *Handbook of research on*

- educational communications and technology (pp. 773-809). New York, NY: Lawrence Erlbaum Associates.
- Shaffer, D. W., Basson, A., and Nussbaum, M. (2000). The concept map as a comprehension assessment tool: Evidentiary standards for a new generation of classroom research. *Educational Assessment*, 6(1), 41-71.
- Sherman, L., and Howard, C. (2012). Teacher resistance to technology: A case study of one high school science teacher's struggle to integrate technology into her classroom practice. *Journal of Science Education and Technology*, 21(4), 425-435.
- Shute, V. J., and Kegelmeyer, C. (2013). Effectiveness of video games in the learning sciences: A review of the literature. *Journal of Educational Psychology*, 105(2), 275-29
- Smetana, L. K., and Lawless, K. A. (2010). Integrating simulation games into secondary science classrooms: A review of the literature. *Journal of Science Education and Technology*, 19(1), 38-48.
- Smith, J. A. (2016). *Qualitative psychology: A practical guide to research methods*. California: SAGE Publications Ltd.
- Smith, M. K., and Blankinship, S. L. (2000). Teaching for visual literacy: *Using visual thinking strategies in the classroom*. Alexandria, VA: ASCD.
- Stieff, M. (2011). Using simulation to support scientific inquiry. *The Science Teacher*, 78(2), 40-45.
- Su, Y., and Grady, J. (2017). Pedagogical affordances of educational simulations: A review of the literature. *Educational Research Review*, 21, 90-103.
- Sung, E.-Y., and Mayer, R. E. (2010). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist*, 45(1), 18-22.
- Tallvid, I. (2016). Teacher resistance to new technologies in education: A critical review of the literature. *Educational Research Review*, 17, 1-12.
- Thompson, A., Simonson, M., and Hargrave, C. (1996). *Educational technology research: A guide*. Boston: Allyn and Bacon.
- Venkatesh, V., and Bala, H. (2008). Technology acceptance model 3 and a research agenda on interventions. *MIS Quarterly*, 32(3), 579-604.
- Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, Massachusetts: Harvard University Press.
- Wang, W., Sun, Y., and Chen, Q. (2019). Integration of technology, pedagogy and content knowledge (TPACK) for fostering primary teachers' professional development in science education. *International Journal of Science Education*, 41(13), 1808-1832.


- Warschauer, M., and Ames, W. (2018). *International handbook of technology and education*. New York: Springer.
- Weber, R. P. (2004). Basic concepts in quantitative research. *Educational Research Quarterly*, 27(4), 3-16.
- Weller, M. (1996). *Educational technology in practice*. Berkshire: Open University Press.
- Wieman, C. E., Perkins, D. K., and Gilbert, S. K. (2010). *Transforming science education*. London: Pearson Education.
- Wilkerson, M., Andrews, R., Shaban, H., Laina, R., and Gravel, M. (2016). Experiences with technology-integrated professional development: A case study of one school district's attempt to support STEM teachers. *Journal of STEM Education: Innovations and Research*, 17(1), 1-12.
- Windschitl, M. (1998). The relationship between constructivist instruction and student learning. *Educational Psychologist*, 33(4), 173-180.
- Woodward, A., Roth, W.-M., and Tobin, K. G. (2023). Learning science through debriefing after simulations: Promoting metacognition and problem-solving. *Science Education*, 107(2), 393-424.
- Xu, X. (2023). A review of research on active learning in higher education: From theory to practice. *Active Learning in Higher Education*, 24(1), 1-17.
- Yildiz, K. (2011). Investigating the factors affecting teachers' use of ICT in a self-determined learning approach. *Computers and Education*, 57(3), 1812-1821.
- Zhao, Y. (2003). Changing conceptions of teacher professional development. *Educational Researcher*, 32(4), 17-20
- Zimmerman, D. H. (2006). Self-regulation and information technology: At the crossroads of new media. In D. H. Zimmerman and C. D. Forness (Eds.): *Handbook of self-regulation of learning and performance* (pp. 482-501). Mahwah, NJ: Erlbaum.

APPENDICES

Appendix 1: Introductory letter from BUSE

P Bag 1020
BINDURA
ZIMBABWE
Tel: 0271-7531 ext 1038
Fax: 263-71-7616

CEMS DEPT



BINDURA UNIVERSITY OF SCIENCE EDUCATION

Date:

TO WHOM IT MAY CONCERN

NAME: BIGBOY GORA REGISTRATION: B214027B

PROGRAMME: M.Sc.EDMAE PART: 2.1


This memo serves to confirm that the above is a bona fide student at Bindura University of Science Education in the Faculty of Science Education.

The student has to undertake research and thereafter present a Research Project in partial fulfilment of the M.Sc.EDMAE programme. The research topic is: The research topic is: Science teachers' Perceptions on the use of interactive Simulations to foster critical thinking skills

In this regard, the department kindly requests your permission to allow the student to carry out his/her research in your institutions.

Your co-operation and assistance is greatly appreciated.

Thank you



Y Mudavanhu (Dr.)
CHAIRPERSON - CEMS

Appendix 2: Approval letters

RAND PREPARATORY AND COLLEGE NPC
 74 Sixth Avenue
 Bezuidenhout Valley
 2094
 Telephone: (011) 618-3331/2
 Web Site: www.rand.schools.co.za

PO Box 66211
 Broadway
 2020
 Fax: (011) 624-2420
 e-mail: info@randschools.co.za

5 January 2024

To whom it may concern

Re: Research Approval Letter


Permission to conduct academic research at the two Rand schools has been granted to the following researcher:



Student Name: Bigboy Gora
 ID Number: 6805295321182
 Tertiary Institution: Bindura University of Science Education, Zimbabwe.
 Programme of Study: MSc.Ed. Measurement, Assessment and Evaluation.
 Student Number: B214027B
 Research Topic: Science teachers' perceptions on the use of interactive simulations to foster critical thinking skills.

Period of Research granted: January 2024 to 30 September 2024

The permission is subject to the following conditions:

- Ethical considerations have been fulfilled- informed consent forms signed by respondents.
- The study may involve science teachers only.
- The study is conducted after school or over the weekend by arrangement.
- No learners may be involved in the study.
- No reference to the school's name may be made in the final research report.

Yours sincerely

 Mr B Harris
 Executive Headmaster

Executive Directors: BA Harris (CEO), WM Harris
 Company Registration No: 21039/040215/08 NPO Registration: 130-135 NPO

SA COLLEGE PRIVATE SCHOOL
 Corner Johannes Ramokhoase, Hospital and Edmond streets
 P.O. Box 26789
 Arcadia, Pretoria 0007
 South Africa

Tel: +27 12 326-1580
 Fax: +27 12 326-2581
 admin@sacps.co.za

19 January 2024


To whom it may concern


Re: Research Approval Letter

This letter serves to confirm that permission has been granted for the following researcher to do research at the school:

Name of Researcher: Dighoy Gora
Institution of study: Bindura University of Science Education
Topic of Research: Science teachers' perceptions on the use of interactive simulations to foster critical thinking skills.

The above researcher is granted permission to interact with science teachers only in the form of a survey and one to one interviews.

Kind regards,

 Dr A. Mutigwa
 Deputy Principal (Senior Phase)
 0845001044



Dominican CONVENT SCHOOL

10 January 2024

To whom it may concern

Re: Academic research approval for Mr Bigboy Gora


This is to confirm that Bigboy Gora, RSA ID: 6805295321182, has been granted permission to conduct academic research at the school



Institution of study: Bindura University of Science Education, Zimbabwe.
 Programme of study: MSc:EDMAE (Measurement, Assessment and Evaluation)
 Student Number: R214027B

Research Topic: Science teachers' perceptions on the use of interactive simulations to foster critical thinking skills.

This permission is subject to the researcher presenting "informed consent" forms to the prospective respondents at the school who may participate in the research study voluntarily. Interaction is strictly restricted to science educators only. The research may only be done after school or during weekends.

Kind regards,
 Malcolm Bwile
 Deputy Principal
 Natural Sciences and English Educator
 Email: mbwile@dominican.co.za


 Dominican Convent & School
 Pre-Primary, Primary
 P.O. Box 33818
 JEPPESTOWN
 2043

Dominican CONVENT SCHOOL
 1990 MEMBERSHIP 619-004-1470
 Established in Catholic Education Since 1988
 1990 MEMBERSHIP 619-004-1470
 1990 MEMBERSHIP 619-004-1470
 1990 MEMBERSHIP 619-004-1470

The above and any attached documents are property of Dominican Convent School. Any unauthorised use or reproduction is illegal. The school and its members are not responsible for any damage or loss of any kind. The school and its members are not responsible for any damage or loss of any kind. The school and its members are not responsible for any damage or loss of any kind. The school and its members are not responsible for any damage or loss of any kind.

Appendix 3: instrument 1 - Interview Survey

QUESTIONS TO BE ANSWERED BY PHYSICAL SCIENCE TEACHERS

- 1 **Gender:**
 - Male
 - Female

- 2 Number of years of Science teaching experience
 - < 5 *years*
 - Between 5 and 10 years
 - More than 10 years

- 3 I am familiar with Interactive Simulations.
 - Yes
 - No

- 4 How do you define critical thinking?

- 5 To what extent do you believe critical thinking skills can be taught?

		Strongly Disagree	Disagree	No Opinion	Agree	Strongly Agree
6	I use simulations in my class to help students understand changing events.					
7	I use simulations in my class to help students effectively understand scientific concepts.					
8	I use simulations in my lessons to meet next generation scientific standards					
9	I use simulations to improve students' understanding of an experimental process.					
10	Simulations help my students to reflect on scientific phenomena					
11	Simulations offer my students the opportunity to make judgments about different aspects of scientific phenomena.					
12	Most of my colleagues use interactive simulations in their Science lessons.					
13	My colleagues, principal, parents and learners expect me to use interactive simulations.					

14	Critical thinking skills are important for my students' analysis and decision making skills, both now and in their future roles in society.					
15	Interactive simulations promote critical thinking skill.					
	To what extent have the following factors influenced your use of digital Interactive simulations in your science classroom?	Does Not Influence	Slightly Influences	Somewhat Influences	Greatly Influences	I have no opinion
16	Lack of skills/experience					
17	Confidence					
18	Insufficient pedagogy					
19	Lack of professional development/Insufficient training on technology					
20	Lack of support					
21	Insufficient access or maintenance to technology					
22	Restrictions in educational environment or curriculum					
23	Too little follow-up after training					
24	Too difficult					
25	Personal preferences					
26	Standardised assessment					
27	Pressure from people whose opinions I value					
28	Enjoyment for both myself and my learners					
29	Habit towards innovation and new technologies					

30 Which of the following methods do you use most frequently to assess your students' critical thinking skills in science (select all that apply):

- Multiple-choice tests
- Open-ended essay questions
- Real-world problem-solving activities
- Group projects and discussions
- Portfolios or collections of student work
- Other (please specify)

- 31** On a scale of 1 (not effective) to 5 (highly effective), how effective do you consider each of the above methods in assessing students' critical thinking skills in science?
- 32** Are there any particular challenges you face in effectively assessing critical thinking skills in science using your current methods? If so, please elaborate.
- 33** In your opinion, what are the most important characteristics or indicators of strong critical thinking skills in science students?
- 34** To what extent do your assessment methods for critical thinking incorporate elements of technology, such as interactive simulations or online tools?
- a. Not at all
 - b. Occasionally
 - c. Frequently
 - d. Always
- 35** On a scale of 1 (strongly disagree) to 5 (strongly agree), how much do you agree that your school provides adequate time and resources for you to effectively integrate interactive simulations into your science lessons?
- 36** Which of the following forms of professional development on using simulations for critical thinking would you find most beneficial (select all that apply):
- a. Hands-on workshops with practical experience
 - b. Online courses or tutorials
 - c. Peer coaching and collaboration with experienced colleagues
 - d. Access to a network of science teachers using simulations
 - e. Other (please specify)

- 37 To what extent does your school offer adequate technical infrastructure and support (e.g., reliable internet, technology troubleshooting) for the smooth and effective use of interactive simulations in your classroom?
- a. Not at all
 - b. Somewhat
 - c. To a moderate extent
 - d. To a great extent
 - e. Completely
- 38 **Do you agree or disagree with the following statement: "My school leadership actively encourages and values the use of interactive simulations for fostering critical thinking in science education"?**
- a. Strongly disagree
 - b. Disagree
 - c. Neutral
 - d. Agree
 - e. Strongly agree
- 39 Which of the following pedagogical practices do you most commonly utilize when integrating interactive simulations for critical thinking development in your science lessons (select all that apply):
- a. Guided scaffolding and questioning during simulation use
 - b. Collaborative analysis and discussion of simulation data and results
 - c. Open-ended inquiry and problem-solving tasks based on simulation scenarios
 - d. Reflection activities and student self-assessment after simulation use
 - e. Connecting simulation findings to real-world contexts and ethical dilemmas

40 In your opinion, how important is it for teacher professional development on using simulations to include specific training on effective associated pedagogies, such as inquiry-based learning and collaborative tasks?

- a. Not important at all
- b. Somewhat important
- c. Moderately important
- d. Very important
- e. Essential

41 **On a scale of 1 (strongly disagree) to 5 (strongly agree), rate yourself on each of the following TPACK dimensions:**

- a. Technological Knowledge (TK)
- b. Pedagogical Knowledge (PK)
- c. Content Knowledge (CK)
- d. Technological Pedagogical Knowledge (TPK)
- e. Pedagogical Content Knowledge (PCK)
- f. Technological Content Knowledge (TCK)
- g. Technological Pedagogical and Content Knowledge (TPACK)

Appendix 4: Instrument 2- Interview Questions – Semi Structured

Thank you for taking the time to participate in this interview. You should have received a copy of the online consent form. Do you have any questions concerning the information you have read on the online consent form?

Based on the online consent form, do you give your consent to participate in this research interview and the recording of the interview? This interview should take us anything between 30 minutes and one hour.

Semi-structured interviews will be used for data collection. This method facilitates consistency and flexibility in exploring teacher perceptions and practices as it is sufficiently structured to address specific interview questions while also leaving room for teachers to offer new meanings (Galletta 2013).

Main research question:

How do teacher perceptions shape the use of interactive simulations for fostering critical thinking?

Sub-research question	
What are the factors that influence the use of interactive simulations by science teachers?	
1	Do you have access to the technological resources such as computers, tablets, or interactive boards, wi-fi connectivity, to effectively integrate simulations into your lessons?
2	Have you received training in utilising interactive simulations as part of your professional development?
3	How well do interactive simulations align with the existing science curriculum, and do you feel that these simulations support the curriculum?
4	Are there any perceived institutional or cultural barriers within your school system that may hinder the adoption of innovative teaching practices, such as the use of interactive simulations?
5	How do you adapt your use of interactive simulations to accommodate students with different learning styles (e.g., visual, auditory, kinaesthetic)? Have you encountered any specific challenges in this regard?
6	What are the main challenges you face when using simulations in your classroom? Are there any technological, logistical, or pedagogical hurdles you encounter? Conversely,

	what unique opportunities do simulations present for enhancing student learning and engagement?
--	---

Sub-research question	
What are the perceptions of science teachers on the use of interactive simulations to foster critical thinking skills?	
7	How do you define critical thinking in the context of science education, and how does this definition influence your instructional strategies with interactive simulations?
8	Can you share any anecdotes or specific instances where you witnessed a notable improvement in a student's critical thinking skills attributable to the use of interactive simulations?
9	In your opinion, are there specific topics or concepts in science where interactive simulations have shown greater effectiveness in promoting critical thinking skills?
10	In your opinion, what role do interactive simulations play in developing students' metacognitive skills, particularly their ability to reflect on and regulate their own thinking processes?

sub-research question**What are the methods used by science teachers to assess critical thinking skills?**

11	Do you employ any formative assessment techniques to continuously gauge students' critical thinking development throughout the course of the year? What are some of your techniques?
12	Have you ever adapted assessments to accommodate different learning paces, allowing students to demonstrate critical thinking at their own pace?
13	How do you provide feedback to students during and after interactive simulation activities to support the development of their critical thinking skills?
14	Are there any specific challenges or opportunities you have encountered when assessing students' critical thinking skills after incorporating interactive simulations into your teaching?

Sub-research question**How can schools help science teachers to use interactive simulations to foster critical thinking?**

15	What specific types of support or resources provided by your school have been most helpful in your efforts to effectively integrate interactive simulations for fostering critical thinking skills in science education?
16	In your opinion, how can school leadership and administration best create a school culture that encourages and values the use of interactive simulations for critical thinking development in science?
17	Imagine your ideal scenario for school support in using simulations for critical thinking development. What resources, professional development opportunities, or changes in school policies would be most beneficial for you and your colleagues in this regard?
18	Thinking beyond your own school, if you could design a model for broader-scale implementation of effective simulation-based learning to foster critical thinking in science education, what key elements would it include? How could schools and other stakeholders collaborate to make this a reality?

Thank you for taking the time to participate in this interview. If I have any additional questions, would I be able to contact you again?

I will summarize my analysis of this interview and would like to send it to you to check that I have accurately represented your ideas.

APPENDIX 5: Teacher invitation to participate in the research and consent form

Dear

My name is Bigboy Gora and I am a Masters student at Bindura University of Science Education. I am conducting a research study as part of the requirements of my degree in Measurement, Assessment and Evaluation, and I would like to invite you to participate in this study.

The topic of my research is *Science teachers' perceptions on the use of Interactive Simulations to foster Critical Thinking Skills*.

I am inviting you to participate in this research because you currently teach grade 12 Physical Science which entails the teaching of the Photoelectric Effect.

Please read the attached teacher informed consent form carefully before you make any decision to participate. If you have any questions about the study, you may contact me at mbgora@gmail.com.

If you would like to participate in this study, send a reply e-mail to me directly at mbgora@gmail.com stating the words, "I consent." Please kindly attach the signed consent form below.

Regards,

Bigboy Gora, Masters student at Bindura University of Science Education

5.2 CONSENT FORM FOR PARTICIPATION IN A RESEARCH STUDY

Topic of Study: *Science teachers' perceptions on the use of Interactive Simulations to foster Critical Thinking Skills*

About this Form:

This form is called a Consent Form. It will give you information about the study so that you can make an informed decision about whether or not you would like to participate.

Eligibility

To participate in this study you must be a Physical Sciences educator currently teaching grade 10 to 12 at a school in the Bedfordview ieb Cluster and you must be above the 18 years and above in age.

Purpose of the study

I am conducting this research study to gain a greater understanding of educators' perceptions on the effectiveness of interactive simulations in promoting critical thinking skills. This is expected to help guide the use of these educational strategies in teaching Physical Science and possibly highlight areas for professional development.

Study location and duration

The study will consist of a one to one interview at your school or any other location convenient to you. The interview will last a maximum of 60 minutes.

Your role

Your role in the study will be to openly and honestly answer a number of semi-structured interview questions posed to you. The questions will include some demographic information. The interviewer will, with your consent, record the responses and transcribe them verbatim at a later stage.

Benefits of being in the study

Your participation will pave way for more research and enrich the body of knowledge on the attitudes and beliefs of Science teachers regarding the efficacy of interactive simulations as instructional tools. There is no monetary benefit associated with your participation.

Protection of personal data

All the information you will supply will solely be for purposes of this study. None of your information will be shared with any third parties. All the recordings and notes will be kept securely and shared with you. Neither your name nor your school will be mentioned expressly in the research findings of the report.

Termination of participation

Your participation in this study is entirely voluntary. If at any stage of the research you feel you no longer want to involve yourself then you will be free to drop out without any prejudice whatsoever.

Questions and clarification

If you have questions at any point then please feel free to contact me at: mbgora@gmail.com
mobile phone:+27769414210 . You are also free to contact my supervisor: Dr Young
Mudavanhu, email: ymudavanhu@buse.ac.zw

Summary of informed consent:

By agreeing to participate in this study, you are agreeing that:

- you have read this consent form (or it has been read to you) and you have been given the opportunity to ask questions, and that the questions have been answered to your satisfaction;
- you have been informed of potential risks and they have been explained to your satisfaction;
- you are 18 years of age or older;
- your participation in this research is completely voluntary;
- you may leave the study at any time; if you decide to stop participating in the study, there will be no penalty to you, and you will not lose any benefits to which you are otherwise entitled.

SUBJECT STATEMENT OF VOLUNTARY CONSENT

I have read and understood this form and I am willing to participate in the research interview described above. The general purposes and particulars of the study as well as possible inconveniences have been explained to my satisfaction. I understand that I can withdraw at any time.

Participant Signature: _____

Date: _____

By signing below I indicate that the participant has read and, to the best of my knowledge, understands the details contained in this document and has been given a copy.

Signature of Person Obtaining Consent: _____

Date: _____