FACULTY OF EDUCATION

Cape Peninsula University of Technology

SCHOOL OF POSTGRADUATE STUDIES AND RESEARCH

THE RELATION BETWEEN GRADE 10 LEARNERS' MATHEMATICAL KNOWLEDGE AND THEIR UNDERSTANDING OF EQUATIONS OF MOTION IN PHYSICAL SCIENCES

Research Project (Thesis) in fulfilment of the requirements for the Master of Education degree

Name: Zingisa Mabangula

Student number: 219494401

Faculty of Education

Supervisor: Prof C.E. Ochonogor

Co-Supervisor: Dr O. Koopman

DECLARATION

Upon submitting this thesis electronically, I, Zingisa Mabangula, declare that the entire content of this work is mine (unless otherwise stated), that its reproduction and publication by the Cape Peninsula University of Technology will not violate any third-party rights and that I have never, beforehand, submitted it to another institution for a qualification or an award.

Date: __2023____

ACKNOWLEDGMENTS

My profound gratitude goes to the Cape Peninsula University of Technology, Mowbray Campus for giving me this opportunity to fulfil my dream of studying towards a master's degree in education. In addition, I would also like to extend my gratitude to those that have been part of the journey since the beginning--my mother, for her consideration, support and patience and friends for their unrelenting encouragement throughout my studies, the schools and science teachers who welcomed me with open arms to conduct the study and lastly, my supervisors, Pro C.E. Ochonogor and Dr O. Koopman whose guidance and expertise made it possible for me to complete my studies.

ABSTRACT

One of the biggest challenges learners encounter in science education is the lack of mathematical understanding and its relation to concepts in physics. This results in a poor understanding of mathematically demanding concepts like equations of motion. Published research reports similar trends in physics programmes at university. One of the main reasons for this is the fact that at schools, science and mathematics are seen as two distinct knowledge fields, which results in teachers and learners failing to make the necessary connections between the disciplines during the teaching and learning process. As a result, teachers at secondary level do not recognize that many of the learners enter the Further Education and Training (FET) science phase, in grade 10, with limited applications of mathematical knowledge in science from the previous grades. The purpose of this research in which the teacher and the researcher were the same person, was to see if it is possible to make teaching science more effective. This was done by investigating the effect of a teaching strategy that is learner-centred, conforming to the theory of social constructivism that endeavours to accentuate the mathematics required in understanding equations of motion in hopes of improving learner understanding and achievement as compared to the conventional traditional teaching style that dominates physical science classrooms around South Africa. Informed by Kiray's balance model as the theoretical framework, the aim of the study was to establish the relation between grade 10 learners' mathematical competency and their understanding of equations of motion in physical sciences. Methodologically, the study adopted a mixed-method approach, where the quantitative aspect was a quasi-experimental non-equivalent pre-test-post-test control group research design as well as a qualitative data collection approach. Quantitatively, the data collection instruments utilized included the Equations of Motion Achievement Test (EoMAT) and Mathematics Ability Test (MAT) while interview questions were designed for a few selected participants to generate qualitative data that gleans for insight into the learners' experience of being subjected to the intervention teaching strategy.

Because of the Covid-19 crisis and the safety protocols put in place by the WCED, the groups for data collection had to be smaller. Consequently, the researcher recruited 18 grade 10 research participants for the experimental group and 18 participants for the control group, giving a total of 36 research participants (N = 36). Both (experimental and control) groups took the EoMAT and MAT as pre-tests. The EoMAT and MAT had total mark scores of 70 and 50, respectively. The pre-tests indicated the learners' initial performance level prior to the four-week intervention. In the experimental school, the learners' scores in the MAT during pre-test

were used to categorize them into high, average, and low mathematical abilities. Only the EoMAT was administered as a post-test at the conclusion of the 4-week intervention to compare the effects of the collaborative approach (group approach) intervention teaching strategy that emphasizes the mathematics required for conceptual understanding of equations of motion (experimental group) and teachers' conventional teaching (control group) on learner performance.

According to the Pearson product moment correlation, the EoMAT and MAT pre-tests were strongly correlated, $r(34) = .7999$, $p < .00001$. An independent t-test was run on the EoMAT post-test scores, and the following were obtained. The 18 participants who received the intervention in the experimental group ($M = 36.89$, $SD = 8.47$) compared to the 18 participants in the control group ($M = 23.61$, $SD = 5.85$) demonstrated significantly better improvement in the EoMAT post-test scores, $t(34) = 5.47$, $p < .00001$.The results from the experimental focus group interviews also indicated similar findings--- they were exposed to a teaching strategy that may be effective when teaching certain physical science topics in grade 10 classrooms. The implications of the results obtained are discussed.

TABLE OF CONTENTS

Chapter 2 – REVIEW OF RELATED LITERATURE

Chapter 3- RESEARCH METHODOLOGY

Chapter 4 - RESULTS

Chapter 5 – Discussion of Results, Conclusions, and Implications of the study

CHAPTER 1

INTRODUCTION TO THE STUDY

1.1 Introduction

Several secondary school physical science learners have a problem in identifying and applying the fundamental mathematical concepts that they have previously learnt in solving science problems (DBE 2014-2019). Learners do not seem to relate the two fields of knowledge. Published research reports similar trends in physics programmes at university level. Mathematics becomes a necessity if learners and students are to master all levels of physics, i.e., it will be difficult to study physics without the sound basics of mathematics (Phage, 2015). Reddish and Kuo (2015) refer to mathematics as the language of physics. Reddish (2005) stated that physicists blend conceptual physics with mathematical skills and knowledge and use them to interpret and solve physics problems using relevant equations and graphs. For instance, in mechanics---particularly kinematics, different aspects from mathematics such as knowledge of functions and the solving of equations---algebraic formalism is combined with physics concepts (Phage, 2015). If this problem is not resolved at the foundation level, it persists until tertiary level, as witnessed from several published reports.

As mentioned from the previous section, it is at grade 10 level where an enduring foundation for physics and chemistry for physical sciences should be laid without losing sight of the mathematical background of the learners. The focus of this study was to investigate the relation between Grade 10 learners' mathematical knowledge and their understanding of equations of motion in physical sciences. In this chapter, the researcher defines and discusses the following (1.2) rationale of the study, (1.3) motivation and statement of the problem, (1.4) statement of the problem, (1.5) aims and objectives of the study, (1.6) research questions, (1.7) hypotheses, (1.8) research methodology, (1.9) delimitations of the study, (1.10) limitations of the study (1.11) definition of key terms (1.12) significance of the study and (1.13) Summary

1.2 Rationale

The knowledge and beliefs science teachers hold about the world have a direct bearing on all aspects of their teaching. More specifically, these believes directly impact on how teachers teach which directly influence what their learners learn in the science classroom (Basson and Kriek, 2012). A direct consequence of such teaching and learning inevitably affects the way learners perform in assessments. The way that teachers personally view the subject has an impact on the goals they set for their learners, as well as the procedures they use to implement a curriculum (Basson and Kriek, 2012). The curriculum also plays a crucial role in learner performance as it informs teachers of the exact content knowledge they should be teaching, more so in certain concepts compared to others (Koopman, 2017). For the various subjects, the Curriculum and Assessment Policy Statement (CAPS) document provides the philosophical framing in which a more learner-centred approach must be followed in the delivery of the content during lessons. This means the learners should be actively involved during the lessons as well (DBE, 2011). This is extremely important when it comes to physical science which tends to be an extremely demanding subject, not only for the teacher but for the learner as well (Kaptan and Timurlenk, 2012). One of the main reasons why teachers and learners consider physical science as demanding is because physical science is often out of touch with the everyday lives of the teachers and learners.

Personal knowledge that teachers and learners bring into the classroom, often referred to as prior knowledge---an assortment of abstracted residue that has been framed from one's everyday encounters has an influence on their behaviour in the classroom. The individual brings various pieces of foundational information, intentionally or subliminally to each resulting experience, and use them to associate or cement new knowledge about science to old ideas and facts (Apata, 2019). Background knowledge in science and science education alike often entails knowledge of science concepts and mathematical knowledge from previous grade/s or level/s (Phage, 2015; Phage et al., 2017). Subjects like physical sciences in general, require extensive background mathematical knowledge to help learners understand the new knowledge to be taught (Redish,2005; Phage, 2015; Redish and Kuo, 2015; Ogunkunle and Obafemi, 2013; Phage et al., 2017; Apata, 2019; Djudin, 2020). Research over the last two decades has shown that learners entering the physical science classroom with inadequate mathematical knowledge, appear to struggle in solving most science problems they encounter in the science classroom, especially in the physics part of physical sciences (Iwuanyanwu, 2018). Those learners who struggle to solve physics problems they encounter in the classroom often struggle with transferring what they have learned from the mathematics class to physics (Djudin, 2020). The lack of adequate mathematical knowledge and its proper application in science is an issue that negatively affects academic performance and therefore continuously plaguing the South African science education landscape, particularly in the physics part of physical sciences (Govender, 2007; Phage, 2015; Phage et al., 2017).

In 2019, around the time where this study was conceived, it had been evident from the 2014-2019, National Senior Certificate Physical Science National Diagnostic Reports which indicated that learners, often, experience some difficulties with concepts from paper one, where mechanics physics concepts are assessed. More specifically, in topics such as: newton's laws of motion, vertical projectile motion, momentum and work, energy and power (Q2, Q3, Q4 and Q5), the average marks obtained expressed as a percentage have been fluctuating between 45-67%, 46-63%, 40-64 % and 40- 57% respectively for the academic years 2014-2019 (DoE, 2020). The foundational knowledge for these topics is covered in grade 10, where the focus is on concepts such as displacement, velocity, and acceleration but the relationship between them which requires a great deal of mathematical background knowledge (DBE, 2011). These concepts cover a subsection of mechanics referred to as equations of motion. According to Basson and Kriek (2012), participants from their study viewed equations of motion as one of the most difficult topics to teach at grade 10 level, alongside with topics such as Waves. These concepts form pre-requisite knowledge for understanding concepts such as Force, Vertical Projectile Motion, Momentum and Energy in the subsequent grades and are highly dependent on a proper mathematical background (Ogunkunle and Obafemi, 2013). The reason for this is the utilisation of a spiral methodology that has been prescribed by the National Curriculum Statement (NCS) and its subject specific policy document, CAPS to empower concept progression and concept coherence. Concept progression revolves around initially introducing a concept in a specific grade and the afterwards returning to that concept in later grades, building on it while conceptual coherence involves making links among topics in just one specific grade (Bason and Kriek, 2008).

According to the diagnostic reports, in the section of Vertical Projectile Motion, the graph sketching skills of many Grade 12 candidates are often quite poor, and learners often experience problems with the signs of velocity and acceleration in their substitutions into the relevant equations of motion. Learners also often experience problems with interpreting displacement-time, acceleration-time, and velocity-time graphs in the context of physics in general. This is reported by Phage (2015) and Phage et al., (2017) as they posit that students find it difficult to derive the values of mechanics concepts from the given graphs, to relate one type of mechanics graph to another and to interpret the gradient of a graph or the area under a graph (DoE, 2020). The question that begs here is 'where does the problem originate from?'

Literature indicates that most of the time, during the teaching process, several science educators tend to assume that students and learners already possess the required mathematical knowledge and skills and expect them to transfer these to physics independently, however this is not the case (Reddish, 2005; Phage et al., 2017). Furthermore, they do not recognise that many of the learners enter the Further Education and Training (FET) phase, in Grade 10, with limited knowledge in mathematics obtained from the previous grades but are now exposed to mathematics that are fundamental to understanding science. In addition, these learners also suddenly become exposed to science equations whose origins and meanings are unclear to them, let alone being able to interpret and utilize them mathematically. According to Djudin (2020), transferring of mathematical knowledge to physics involves the process of linking and using mathematical facts, concepts, principles, and procedures related to physics problems through the process of horizontal-assimilation and/or vertical-accommodation of the schema (cognitive structures).

Furner and Kumar (2007) however, indicate that there have been cases where science educators acknowledge that one of the problems in science education nowadays, is the "separate subject" or "layer cake" approach to knowledge and skills. Since these educators realised this, they have reported that they do guide students in making connections between science and other disciplines regularly. Due to this Kumar and Furner (2007) further suggest that to remedy this situation, integrating science and mathematics method courses might be the best course of action. Researchers such as Berlin and White (1992), Davison et al., (1995); Lederman and Niess (1997, 1998); Roebuck and Warden (1998); Huntly (1999); Lehman (1994); Frykholm and Glasson (2005) & Furner and Kumar (2007) also believe that there is optimism for improving science teaching and student/learner achievement through interdisciplinary instruction, that is, integration of science and mathematics. "Yes, we should integrate mathematics and science wherever it is possible in the curriculum" (Furner and Kumar, 2007:188).

There have been studies that also examined the common difficulties that learners and students often encounter when dealing with mathematically demanding science problems in school and university level alike. For example, studies conducted by Govender (2007); Phage (2015) and Phage et al., (2017) focused on problem solving or the interpretation and comprehension of specific aspects like the sign conventions, properties of graphs in general at university level. Govender (2007) explored the different ways that student teachers conceptualise algebraic sign convention in vector-kinematics. The data gathered indicated the need for physics teachers to be more mindful of both student teachers limited conceptual of vector-kinematics and its associated algebraic sign convention in first-year university physics. Phage (2015) examined the deficits first-year physics students possess in terms of transferring mathematics knowledge and skills when solving kinematics graphs problems. Where the area construct is concerned, most participants were unable to transfer the mathematical knowledge to the physics context. However, regarding the other constructs, the participants generally performed similarly well on gradient, reading coordinates etc. The study further revealed that most participants lacked understanding of basic physics concepts such as average velocity and acceleration. Phage et al., 2017 investigated the factors impacting students' graph comprehension regarding four operations in kinematics graphs. From the study Phage et al. (2017) concluded that problems participants encountered with kinematics graphs are mainly due to the deficits they possess in terms of contextual knowledge that is basic to model of physics and mathematics of linear motion represented by the graphs.

The literature review section of this study explores studies that have investigated certain teaching strategies and methods in an endeavour to find solutions revolving around the issue of mathematics in science, however no study has been conducted at grade 10 level where the aim is to establish the relation between grade 10 learners' mathematical competency and their understanding of equations of motion in physical sciences and to inform how learner achievement in grade 10 can be improved by focusing on equations of motion utilising a learner-centred strategy that accentuates the required mathematical knowledge in South Africa, where most schools have traditional teaching styles and limited learning resources which often impede learning within the South African science education landscape. This study intends to contribute in this regard by investigating the effect of a teaching strategy that is learner-centred, conforming to the theory of social constructivism that endeavours to accentuate the mathematics required in understanding mechanics in hopes of improving student achievement on the aforementioned physical sciences topic. Thus, the study will investigate the relation between mathematical knowledge and skills and grade 10 learners' understanding of equations of motion in mechanics in physical science.

1.3 Motivation

There appears to be a dearth of South African studies looking into the integration of mathematics into the physical science school curriculum. A quick glance through the literature shows how beneficial the integration of mathematics in the pre-service physics sciences curriculum would be for science education. Drawing from my personal experiences as a physical sciences teacher for the last 4 years, data from the national diagnostic reports of the Grade 12 results from 2018-2021, and the Trends in International Mathematics and Science Studies (TIMSS) reports for the last 10 years, shows how physical science learners in South Africa are experiencing various challenges in mechanics, especially in equations of motions, due to a lack of mathematical knowledge. This lack of mathematical knowledge may result in most students being unable to utilize, understand and interpret equations of motion and relevant graphs. If we do not improve a learners' understanding of mathematics at secondary level, that may also persist until university level where most students end up being unable to understand and interpret kinematics and other related physics phenomena or present them clearly in their laboratory experiments as many studies have indicated.

Therefore, due to a significant gap in the literature, I was motivated to undertake this study by investigating how a good understanding of mathematics amongst grade 10 learners can improve their understanding of equations of motions.

1.4 Statement of the problem

In physical sciences, mathematics is used to represent concepts and techniques to describe physical concepts and events (Kiray, 2012; Ogunkunle and Obafemi, 2013; Phage, 2015). Consider an object in motion for example, where the physics governing its motion falls under the concepts of equations of motion which include displacement, velocity, and acceleration. To describe and quantify the object's change in displacement, velocity, or acceleration over time, mathematical concepts and graphs are utilized. Comprehension of such concepts and ideas requires not only an understanding of physical phenomena but also a transfer and re-interpretation of mathematical ideas from the mathematical context to that of physics (Redish, 2005). Due to this fact, research in the field indicates that most of the learning is hindered by the limited understanding of the mathematical concepts that underpin physics which then limits the understanding of the physics subject matter (Phage, 2015; Ogunkunle and Obafemi, 2013). This in turn leads to the inability of the learner and student to successfully solve physics problems mathematically (Phage, 2015).

The researcher, from personal experience as a physical science teacher, understands that during the teaching process physical science teachers focus more on the science side of the content and neglect the mathematics required, due to an oversubscribed curriculum. This especially occurs when teachers utilize teacher-centred strategies which have become conventional in most schools around South Africa. These teacher-centred instructional approaches dominate most physical sciences lessons in South Africa and for the longest time it has been thought that these teaching strategies are perhaps the reason why the mathematical knowledge required has been neglected during physical science lessons (Furner and Kumar, 2007; Phage, 2015; Qhobela and Moru, 2014). To remedy this Furner and Kumar (2007) recommend learner-centred approaches which draw from the constructivist way of hands-on and minds-on way of teaching and learning as opposed to the teacher-centred approach which contributes to problems of integration of mathematics and science in meaningful ways. However, above all else, most educators and researchers prioritize the importance of possessing decent a science and mathematics subject matter if effective instruction of science is to occur (Kriek and Grayson, 2009). This becomes key if the interdisciplinary instruction of science and mathematics is to take place successfully (Kiray, 2012; Baskav, Alev and Karal, 2010).

According to Koopman (2017), a developing concern about the low degree of Subject Matter Knowledge (SMK) and Pedagogical Content Knowledge (PCK) that science educators possess has also been recognized. These concerns accept that a mutilated comprehension of the science subject matter teachers can hinder effective instruction of science. For example, a study conducted by Basson and Kriek (2012) where the level of subject matter science teachers possess around certain South African schools was researched--revealing that science educators in schools from the townships found the substance above their teaching capability. “Teachers’ poor grasp of the knowledge structure of mathematics and science acts as a major inhibition to teaching and learning these subjects” (Kriek and Grayson, 2009:186). The researchers concluded that several teachers in those areas were not qualified or not confident enough to properly teach physical sciences. The poor content knowledge of science teachers and the fact that some teachers are trapped in traditional conventional pedagogies has resulted learners to perceive the subject as difficult (Koopman, 2017). Qhobela and Moru (2011) posit that having proper content knowledge helps teachers make good choices when it comes to the teaching strategies to be utilised. Kriek and Grayson (2009) posit that on top of having sufficient content knowledge, teachers need to learn how to properly teach that content.

Furner and Kumar (2007) have stated, when teaching science, teachers should move away from the straight branch of knowledge area approach and attempt to include the identification of a focal topic and ask what each subject can add to it. This requires possession of an extensive amount of science and mathematical content knowledge if we are talking about the interdisciplinary instruction of the two. However, when it comes to science and mathematics instruction, the deficiency in content knowledge that many teachers possess often impedes them from making the proper links between the two disciplines (Kiray and Kapta, 2012). Even when they do possess an adequate level of science and mathematics subject matter, things are not always that simple. For instance, the issue of a somewhat centralized educational system makes it difficult for teachers to implement new policies, experiment with new, innovative teaching techniques. Thus, in most cases, full autonomy at school level is something most South African teachers do not have.

“Mathematics is commonly referred to as “the language of science” and we typically require our physics students to take mathematics as prerequisites to their study of physics” (Reddish, 2005, :1). Teachers are frequently stunned by the deficits in mathematics learners and students have, despite successful performances in the mathematics classes. When learners and students seem to have trouble with mathematics in physics classes, they may be approached to go study more mathematics. However, utilizing mathematics in science (particularly in physics) is not just doing mathematics. “It has a different purpose – representing meaning about physical systems rather than expressing abstract relationships – and it even has a distinct semiotics – the way meaning is put into symbols – from pure mathematics” (Reddish, 2005:1).

This can be seen at secondary level as well as several science teachers often assume that learners have the necessary mathematical knowledge and skills and expect that they should be able to transfer it to physical science without help from anyone else, which is regularly not the situation (Basson and Kriek, 2012; Phage et al., 2017). Even if teachers possess enough content knowledge for both disciplines, have years of experience in teaching physics from high school to graduate level and have possession of knowledge from relevant research on ‘‘problem solving’’ in physics, teaching students to effectively utilise mathematics in physics in a way that reaches most students still eludes the physics community and science in general (Redish and Kuo, 2015).

At secondary level teachers do not recognize that many of the learners enter the Further Education and Training (FET) science phase, in grade 10, with limited mathematics obtained from the previous grades but are now exposed to mathematics that are fundamental to understanding science, particularly in equations of motion (Basson and Kriek, 2012). In addition, these learners also suddenly become exposed to scientific equations whose origins and meaning is unclear to them, let alone being able to interpret them mathematically.

Even with the computational technology being developed to help simplify mathematical topics that are heavily incorporated in physics learning such as graphs, most rural and township schools around South Africa suffer from a scarcity of resources to implement such teaching and learning programs (Basson and Kriek, 2012; Araujo, Veit and Moreira, 2008; Qhobela and Moru, 2011).”Schools are only as good as their teachers, regardless of how high their standards, how up to date their technology, or how innovative their programs. Long-term, sustainable improvement of mathematics and science education must therefore focus on strengthening teachers” (Kriek, 2009: 186). Grade 10 stands as the grade at which an enduring foundation for physics and other physical sciences should be laid without losing sight of the mathematical background of the learners. It is therefore the problem of this study to establish the relationship between the level of mathematical knowledge on grade 10 learners’ understanding of equations of motion in schools in the Western Cape province.

1.5 Aims and objectives of the study.

The main aim of the study is to establish the relation between grade 10 learners' mathematical competency and their understanding of equations of motion in physical sciences.

The objectives are:

- To establish if there is a statistically significant relationship between Grade 10 learners' mathematical competencies and their understanding of equations of motion in physical science?
- To establish if there is a statistically significant improvement in the performance of learners in equations of motion when exposed to a mathematical enriched instructional strategy compared to those learners exposed to the conventional approach to the teaching of equations of motion?

1.6 Research questions

Main question:

What is the relation between grade 10 learners' mathematical competency and their understanding of equations of motion in physical sciences?

Sub-questions

- Is there a statistically significant relationship between grade 10 learners' mathematical competencies and their understanding of equations of motion in physical science?
- Is there a statistically significant improvement in the performance of learners in equations of motion when exposed to a mathematical enriched instructional strategy compared to those learners exposed to the conventional approach to the teaching of equations of motion?

1.7 Hypotheses

- H_o. There is no statistically significant relationship between achievement in equations of motion and level of mathematical competencies and knowledge by grade 10 physical science learners in this study.
- H_{o1}. There is no statistically significant improvement in achievement in equations of motion between grade 10 Physical Science learners taught with a mathematical

enriched instructional strategy compared to those learners exposed to the conventional approach to teaching.

1.8 Research Methodology

The research questions the study seeks to provide answers to aim and objectives mentioned in the previous sections--it was never going to be enough to solely focus on the quantitative aspect, where data collection is concerned, the qualitative aspect was just as essential. Hence a mixed-method approach was adopted for the study. Mixed methods research helps answer the research questions that cannot be answered by quantitative or qualitative methods alone and provides a greater repertoire of tools to meet the aims and objectives of a study (Doyle, Brady and Byrne, 2009). The researcher sought not only to gather empirical, statistical data and analysis but also the in-depth understanding and its implications where the humane and social aspect are concerned.

Most times, the mixed method approach in research is regarded as the “third methodological movement” and it has been extremely useful where health and social science research is concerned (Doyle at al., 2009). Mixed methods can be described as ‘research methods in which the researchers collect and analyse data, integrate the findings, and draw inferences using both qualitative and quantitative approaches or methods in a single study (Ponce and Maldonado, 2015). This approach to research became a necessity due to the limitations of the sole use of quantitative or qualitative methods and is now considered by many a legitimate alternative to these two traditions (Doyle et al., 2009). Mixed methods studies in educational research allow researchers to appreciate the strength of mixed methods research in dealing with complex educational phenomenon such as the teaching-learning process and work stress often found in the public educational system (Ponce and Maldonado, 2014). In addition, because of their known flexibility, mixed methods are often suitable when investigating complex educational phenomena (Maree, 2021).

There are a number a way in which a researcher can choose to collect data via a mixed methods depending on the nature of his/her study as outlined by several published works such Ponce and Maldonado (2014) and Doyle et al., (2009). Additionally, according to Doyle et al., (2009), to use a particular mixed-methods design, three issues need to be considered. The first decision to be made is regarding conducting the qualitative and quantitative stages concurrently or sequentially. Deciding whether both the methods are given equal priority is another key decision. The third issue is to ascertain where the mixing of the qualitative and quantitative methods will occur. For this study, the decision for the type of mixed method to be used for the study is shown in figure 1.

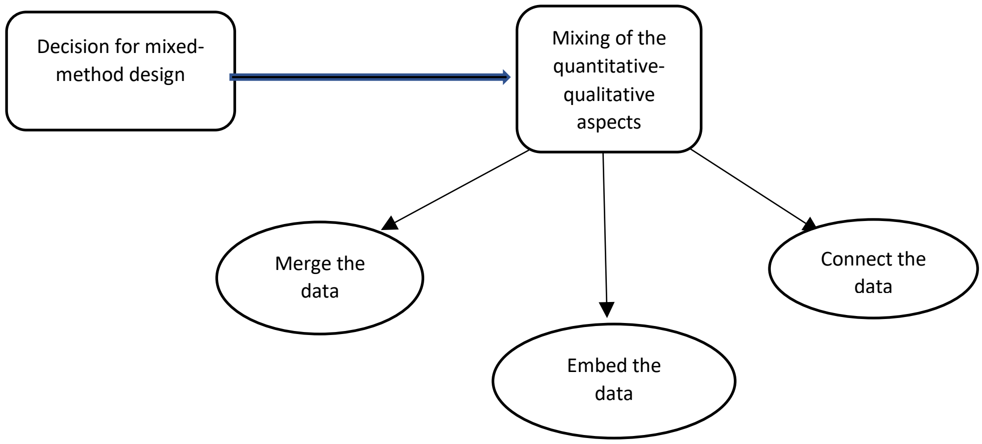


Figure 1: Decision diagram for the mixed method study (Doyle et al., 2009)

The overall structure of the research design for this study draws its elements from the triangulation, complementary design using parallel phases (embedded designs) and explanatory design using sequential phases (quantitative -qualitative). The goal of the triangulation design is to explore the same components of the research problem using both quantitative and qualitative methodologies. To do so, the researcher meticulously designs the entire research process with the goal of addressing these parts of the topic from both a quantitative and qualitative standpoint. This can be accomplished if the measuring equipment and research methodologies used to collect quantitative and qualitative data on the study problem are aligned and complementary (Ponce and Maldonado, 2014). As a result, the data analysis method focuses on these components in order to acquire quantitative and qualitative data so that the problem can be triangulated or considered from multiple perspectives.

The goal of the complementary design is to use one of the research methodologies (qualitative) to compensate for the shortcomings of the other (quantitative) (Ponce and Maldonado, 2014). Because it is the major or primary technique of study, a particular research methodology plays a central role in this design. This is frequently an experiment in which the primary goal is to determine the efficacy of a technique or a novel treatment (Doyle et al., 2009). The experimental design's strength in this example is that it assesses the effectiveness of a treatment on humans. Typically, participants take a pre-test on the phenomenon being studied, then receive treatment, and the outcome is examined with a post-test to see if the treatment was effective (Doyle et al., 2009). However, it has a flaw in that it does not provide a thorough explanation of the treatment or how it works. This happens because the experiment assumes that any change observed in the pre- and post-tests was caused by the treatment. To address, this flaw, a qualitative technique is applied, in which the researcher learns about the experience of persons who received the treatment. The quantitative approach, the experiment, is the primary way of study in this situation, and the qualitative approach is the complimentary method, as it is employed to compensate for the experiment's methodological flaws (Ponce and Maldonado, 2014). The typical designs of triangulation and complementary parallel phases are shown in figure 2.

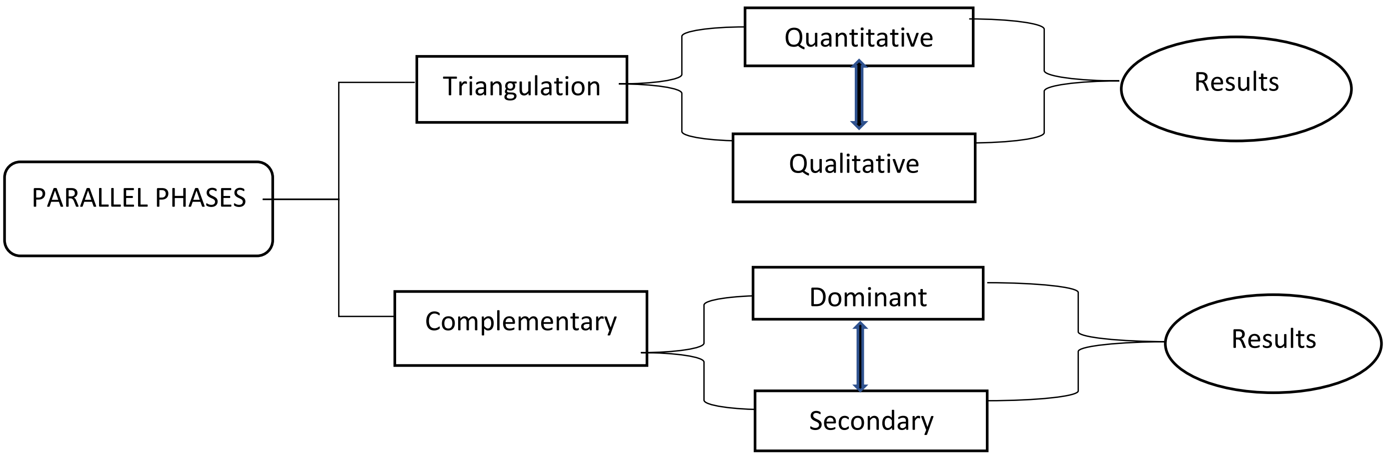


Figure 2: Mixed designs basics (Ponce and Maldonado,2014)

Quantitatively, the study followed a quasi-experimental research design as a true experimental design was impossible due to randomization issues. The participants in both the experimental (treatment) and control (no treatment) groups were randomly assigned thus intact sampling was utilized (Thomas, 2020). Quasi-experimental designs are often used in educational research since learners and teachers are not typically able to be randomly assigned to districts, schools, or classrooms for research (Thomas, 2020).

As required of any study with an experimental design, there was an experimental and a control group since the effectiveness of a treatment was examined as mentioned in the research questions and objectives section. Data collection instruments included the Equations of motion Achievement Test (EoMAT) and Mathematics Achievement Test (MAT) used as pre-tests and post-tests. Pre-test-post-test designs are known for their use in behavioural research, mainly with the aim of comparing groups and/or measuring change resulting from experimental treatments (Dimitrov and Rumrill, 2003). For this study the pre-test and post-test were used to compare the experimental and control groups by measuring the objective mathematical and scientific conceptual understanding of the learners before and after intervention procedures. However, educational settings, as established, are complex natural and social settings where the experiments that can be conducted are quasi-experiments (Ponce and Maldonado, 2014; Thomas, 2020). Hence the need for qualitative data collection. This was done by conducting semi-structured interviews to deepen the understanding of the quantitative data obtained - refer to figures 3 and 4:

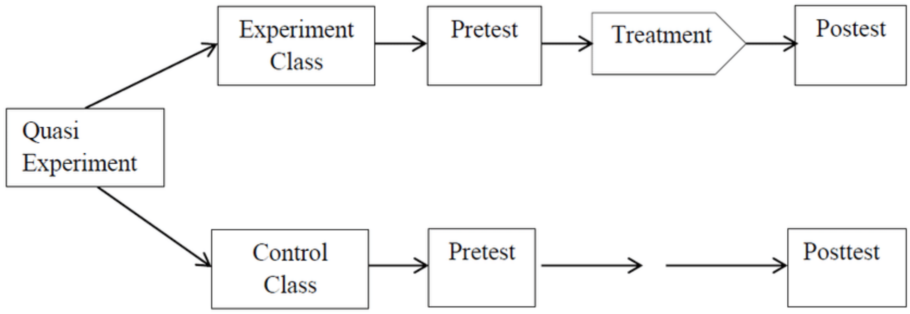


Figure 3: Pre-test and post-test quasi-experimental design (Thomas, 2020)

The study proceeded in two phases: an initial quantitative instrument phase, followed by a qualitative data collection phase, in which the qualitative phase builds directly on the results from the quantitative phase (sequential phases design). This is typal of the explanatory design which is described as a sequential explanatory design consists of two phases, beginning with the quantitative phase and then the qualitative phase, which aims to explain or enhance the quantitative results (Doyle et al., 2009).This means that the researcher begins his study with a research approach (phase I) and uses findings to design a second phase (phase II) but using another research approach (Ponce and Maldonado, 2014). For example, the study began with a quantitative phase and used the findings to design the qualitative phase. The fundamentals of studies with sequential phases are to use a research approach to deeply study the research problem and then use the findings of the first phase and design the second phase (Ponce and Maldonado, 2014). Refer to figure 4.

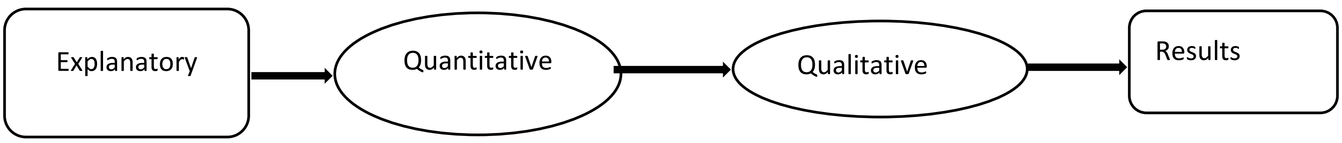


Figure 4: A typical sequential phases design (Ponce and Maldonado,2014)

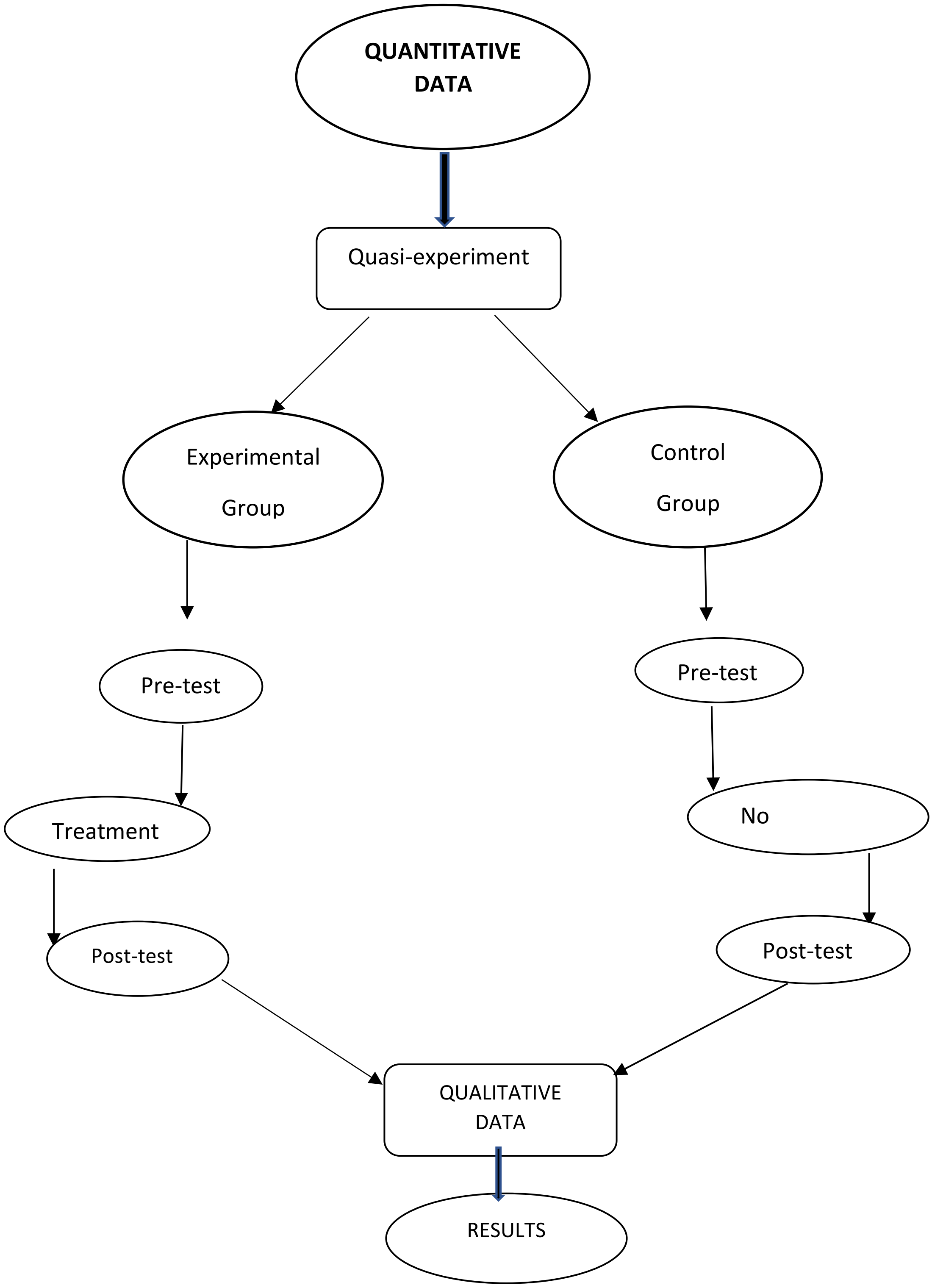


Figure 5: Flow diagram of the overall mixed-method approach for this study.

The goal of this approach was to look at the research problem in its entirety. As seen in the test scores from the pre-tests and post-tests, the quantitative technique is utilized to measure the characteristics and objective features of the problem. The qualitative method is used to investigate the participants' perspectives on the subject under investigation. The qualitative data helps to grasp the quantitative data better, which leads to a clearer, more thorough picture of the topic at hand. The qualitative data helps to interpret the quantitative data, resulting in a clear, full picture of the topic under investigation. The use of quantitative and qualitative evidence allows the argument to reach a stage where there is no dispute about the validity of the argument. Using quantitative and qualitative data allows the argument to reach a point where there is no doubt regarding the findings or the need for rebuttal because a comprehensive picture of the topic has been presented (Ponce and Maldonado, 2014).

If either quantitative and qualitative methodologies cannot be individually used as components of a study, it is assumed that there are existing difficulties whose complexity cannot be thoroughly studied by either. This is especially true in the case of educational issues, which are frequently complicated. First, the nature of the teaching-learning educational phenomenon under investigation is an example of this intricacy. Secondly, the educational systems' cultural contexts in which the investigations were conducted also come with their complexities. Understanding quantitative, qualitative, and mixed methodologies research designs is crucial for successfully implementing mixed research investigations. Simply defined, the problem's complexity cannot be fully deciphered or comprehended from either a quantitative or qualitative standpoint. Studies with mixed methods address problems involving objective and subjective aspects that demand both quantitative and qualitative approaches.

1.9 Delimitations of the study

The study examines the relation between grade 10 learners' mathematical competency and their understanding of equations of motion in physical sciences. These learners will possibly go on to do grade 12 physical sciences and beyond and will need to develop their skills as they engage with the syllabus should they decide to further pursue the sciences. Ideally, the researcher would have preferred a larger sample of participants from two distinct schools, however, due to the circumstances we face on a daily basis due to the crisis of COVID-19, only a few (at least fewer than the proposed sample size) learners enrolled in the subject were approached about participating in the study, and from those learners, only those who signed consent forms were contacted for data collection. The data was collected at the schools the researcher found convenient in terms of proximity and availability.

1.10 Limitations of the study

As the researcher carrying out this investigation, it is important to acknowledge the study's general assumptions and limitations. Firstly, I assume that the learners will have knowledge of equations of motion from physical science and will, to some extent, have covered the necessary basics from the syllabus. However, it is very likely that they will have not. Secondly, I must be acutely aware of my own interpretation and understanding of the use of mathematics in physical science as a teacher so as to not be judgmental about aspects of the way learners usually use mathematics in other science subjects. However, since these aspects may or may not be relevant to the proposed study, this will help me focus the study as I may have an influenced subjective view when taking notes lesson observation, interviews and coding the data. Furthermore, I would like to acknowledge that the teaching and learning process is generally viewed as subjective, transformative, or integrated, and that personal perspective can influence the interpretation of mathematics in physical science.

Since the data will be collected from schools located in areas in proximity and convenient to the researcher, this study will not be a completely accurate reflection of physical science in South Africa as a whole, but merely a specific region in South Africa. Moreover, the participants come from similar backgrounds and communities - thus not representing South Africa's diversity.

Also, this is a quasi-experimental study conducted in an educational setting where it is very hard to have complete control over all the confounding and extraneous variables that may interfere with the relationship between the variables being studied, however the researcher has taken certain steps to account for that.

1.11 Significance of the study

Teaching science, especially physical science in such a way that the mathematics underpinning it is made explicit to the learner, where the teacher assumes the role of a guide instead of the “all-knowing”, where the learner is actively involved during lessons is not something you see every day in South African schools. In this regard, this study intends to contribute, and the information generated may assist us in understanding some of the factors that contribute to the poor state of science education in South Africa, as well as how we can improve teaching or adapt teacher training efforts.

Research has been done in South Africa on the factors contributing to the poor state of science education, but little research has been done on the relation between mathematical competency and their understanding of mechanics in physical sciences at secondary level within a South African context. Since language, qualified teachers, and teaching methods are among the most important contributing factors; it is important to examine the relation between grade 10 learners' mathematical competency and their understanding of mechanics in physical sciences. In South Africa, this study could provide valuable information to a variety of stakeholders, including various teacher training institutions and programs, departments of education, educational reform efforts, schools, teachers, and other researchers.

For the reader, it is important to note there are a few key terms that are repeatedly seen throughout the various sections of this study, and that these outline the central themes of the study. Depending on the research perspective and the literature, some of these terms may have various definitions and some of these definitions are addressed in the various chapters of this study. However, the definitions below provide a clear perspective on how I accepted and interpreted these key terms.

1.12 Definition of key terms

Content Knowledge (CK) and Subject Matter Knowledge (SMK): Content and subject matter refer to areas of creating forums for teaching and sharing knowledge. The words content and subject matter are synonyms and at first would seem to be the same. However, there is a subtle difference in the exact understanding of these words in context. Content, in academic circles, refers to areas of learning and the knowledge within those areas. Subject matter, on the other hand, is more finely described as the actual knowledge and learning to be imparted.

Integrated/Interdisciplinary Instruction: Entails the use and integration of methods and analytical frameworks from more than one academic discipline to examine a theme, issue, question, or topic.

Pedagogical Content Knowledge (PCK): An amalgamation of a teacher's pedagogy and knowledge of content that influences their teaching so that learners are stimulated to understand what they are learning.

Competence: Generally referred to the ability to do something successfully or efficiently. However, for this study we define competency as the ability to comprehend mathematics concepts that they use them efficiently when dealing mathematically demanding science topic.

The Curriculum and Assessment Policy Statement (CAPS): The revised version of the NCS (National Curriculum Statement) of South Africa. CAPS gives teachers detailed guidelines of what to teach and assess on a grade –by- grade and subject-by- subject basis.

1.13 Summary

This study sought to investigate the relation between grade 10 learners' mathematical competency and their understanding of equations of motion in physical sciences. The study is limited to a group of grade 10 learners in Cape Town and focused on the topic of equations of motion in the CAPS grade 10 physical sciences curriculum. The literature argues that physical science learners and physics students have a difficult time making the connection between mathematics and physical science/physics and that teachers and lecturers are sometimes ignorant of this fact or struggle to make this relationship between mathematics and science explicit when teaching. This is due to several reasons of course, mentioned in the literature review section and even though there have been several studies conducted to make teaching science more effective, these studies are mostly international and conducted at university level--almost none are conducted at grade 10 secondary level within the South African educational landscape. Evident from literature, this is a gap that I have identified as I have discovered that the problem probably starts as early as the grade 10 secondary level if not earlier.

1.14 Thesis Outline

Chapter 2: Review of related literature

The researcher places himself within the science educational research domain in this chapter. The literature review in this chapter aims to provide a foundation for underlining the importance of the use of mathematics in the physical science classroom and how it could potentially provide support and solutions to teaching and learning issues in the diverse South African physical science classroom. I also provide a theoretical framework, highlighting the importance from a social constructivist perspective, of how properly teaching the effective use of mathematics in physical science may lead to more engagement in the classroom and the construction of deeper meanings amongst learners.

Chapter 3: Research Methodology

The research design and methods used to conduct this study are described in this chapter. Also discussed in this chapter are sampling, data collection, data analysis, and the role of the researcher in the overall mixed methods research conducted. In the conclusion, the mixed method approach is discussed in terms of its validity and reliability as well as how the requirements were met in the study.

Chapter 4: Results and Data Analyses

The qualitative and quantitative analyses of the EoMAT and MAT and interviews are presented and organized in this chapter. The chapter begins with a summary of the pre-test and post-test of the EoMAT and MAT results of the participating groups. Following that, the transcribed results of the interviews for the experimental group are presented. Thereafter each research sub-question is addressed in terms of the statistical data analyses obtained.

Chapter 5: Discussion of Research Results**,** Conclusions, and Implications of the study

The chapter begins by discussing the quantitative and qualitative results obtained, to see if there is a point of convergence and how that they fit in existing literature. This chapter then concludes with the findings of the study and general observations, reflecting on the challenges encountered during data analyses and interpretations. The last chapter also addresses each of the sub-questions and finally addresses the main research question addressed by this study. Additionally, recommendations for future research will be provided, especially where the South African science classroom is concerned. And in conclusion, the researcher discusses how the results might be used to inform science teachers on their teaching and to influence science teacher training efforts.

Chapter 2

REVIEW OF RELATED LITERATURE

2.1 Introduction

Individual academic disciplines have concerns specific to them and their courses, and science education is no exception. From centralised educational systems to inadequate professional development and insufficient physical conditions of schools (less laboratory opportunities and other important school facilities), from intensive curriculum with little time allocation and for proper science education to instruction of lessons on an information level where learners and students find themselves in passive positions (only listening and writing) while teachers are in active positions (writing on the board and teaching in a classical way). These are some of the problems that plague science education that authors such as Kaptan and Timurlenk (2012), Maree (2021), Phage (2015), and many others in the field of science education have looked into.The importance of prior knowledge is another major factor in science education and science alike that often illudes science educators learners and students. Since scientific knowledge is often viewed as a field of knowledge where newly discovered knowledge builds on from previously known knowledge, learners students are often taught that way as well (Phage et al., 2017). Be at high school level or university level, new content in any science course is taught in a way that builds on from knowledge from the previous level/s (Basson and Kriek, 2012). This means that prior knowledge is crucial if learners and students are to succeed when dealing new content (Phage et al., 2017).

Besides the actual scientific prior knowledge that learners and students require from the previous level/s in order to succeed in understanding new concepts, knowledge from mathematics is often required as well (Phage, 2015). In science, especially physical sciences, principles such as symmetry, reflection, shape and structure reach down to atomic levels. For instance algebra and trigonometry are often required when dealing with problems from chemical change such as balancing chemical equations and equations of motions in mechanics. As a result concerns have often been raised by science educators about the level of understanding of the mathematical aspects of science amongst learners, points in the physical science curriculum where science and mathematics overlap (Kumar and Furner, 2007). Because of this, science educators believe that if a learner is to succeed in physical science, especially in topics such as equations of motion, they require much background mathematical knowledge and skills. Thus, they should be taught in a way that is learner-centred and emphasizes the much-required mathematical knowledge and skills (Phage et al., 2017, Iwuanyanwu and Ogunniyi, 2019).

Allowing the learners to be proactive during the teaching and the learning processes motivates them and increases achievement in both science and mathematics**.** This idea lends itself to the constructivist approach of hands on--minds on learning way of teaching and learning as opposed to the teacher-centred approach which may contribute to problems in a meaningful integration of mathematics and science (Furner and Kumar, 2007)**.** A plethora of literature exists where the importance of overlap between mathematics and science is explored. This study, however, is located within the secondary level education in the South African context. The researcher has recognized this as a gap in literature, more so within the South African context, thus, through this study, he aims to contribute to this regard**.**

Thus, the following primarily focuses on related literature on the importance of the role of mathematics in physical science, particularly in mechanics-- equations of motions and how its use may therefore potentially provide support and solutions to teaching and learning issues in the diverse South African science classroom. A social constructivist theoretical framework is also provided by the researcher for the application of mathematical skills in the science classroom, where the effective application of mathematics may result in a stronger sense of engagement among learners in the construction of deeper meanings and understandings, ultimately leading to improved performance in science.

2.2 The role of mathematics in equations of motion

Mathematical 'inscriptions' such as numbers, graphs, signs, symbols, signs, and sign convention hold great significance in physics as they serve as a tool or technique for expressing physical quantities and solving of physics problems (Govender, 2007). Because physics and mathematics are such closely related subjects, deficiencies in prior content knowledge and competency on these mathematical ‘inscriptions’ often results in poor understanding of key concepts in physics and therefore poor achievement. For instance, a limited pre-requisite content information and graphical abilities may hinder students' graph comprehension in physical science (Phage et al., 2017). Learners may encounter issues with deciphering graphs with regards to physical science in general, particularly in kinematics, also known as equations of motion (Phage, 2015; Phage et al., 2017). They struggle to derive the values of mechanics concepts, such as displacement, velocity, from the given graphs, to relate one type of a mechanics graph to another and to interpret the gradient of a graph or the area under a graph (Phage et al., 2017). They also struggle with sign convention when dealing with vectors from equations of motions in mechanics (Govender, 2007). Sign convention can be described as the arbitrary choice of mathematical representation used as a technique in problem solving--for example, algebraic signs (+) and (–) is used to indicate the direction of motion of the object under observation (Govender, 2007). In mechanics, this involves symbolic representations of algebraic operations and subsequent manipulation and interpretation of those symbols within the context of problem solving in one, two and three dimensions (Govender, 2007). These are just few of many examples that show why mathematics is crucial when one is with dealing physics concepts. One other important aspect of mathematics in physics is the use of basic algebraic operations to derive the standard physics equations themselves to enhance understanding of the physics concepts involved.

According to the CAPS document for grade 10, the topic of equations of motion focus mainly on the acceleration of the object that is uniform and is moving in a straight line and because of this, they are referred to as laws of constant acceleration. The CAPS document explicitly focuses on three main equations (presented below) that grade 10 physical science learners should know.

<u>Grade 10: Equations of motion</u>

$v_f = v_i + at$

$v^2 = vi^2 + 2a\Delta x$

$\Delta x = vi\Delta t + ½ a\Delta t^2$

where Δx = displacement,

v_i = initial velocity,

v_f= final velocity,

a= acceleration and

t= time of motion.

Let me explain what these equations mean ---the first equation of motion: $v = v_i + at$; this equation only focuses on acceleration, time, the initial and final velocities. Let us assume that a body that has mass "m" and initial velocity "v_i". Let after time "t" its initial velocity become its final velocity "v" due to uniform acceleration "a". Now we know that:

Acceleration = Change in velocity/ Time Taken

Therefore, Acceleration = (Final Velocity-Initial Velocity)/ Time Taken

Hence, $a = v - v_i/t$ or at = v-u. Rearranging the equation gives you, $v = v_f + at$. The other two equations can easily be derived from the first one by rearranging the first equation, introducing one other important physical variable: displacement(Δx) and manipulating the combined equations with all the necessary variables using basic algebraic operations. Understanding this not only enhances a learner's understanding of the concepts but also their ability to assess a real-life situation where physics is concerned and know exactly what they need to do with these equations to successfully solve related problems.

Learners, however, struggle greatly when they are required to relate the motion of an object to its variables and algebraic formalism (Govender, 2007). The previous NCS curriculum and now CAPS were developed to urge teachers to utilize a spiral methodology for the knowledge areas. A topic is presented in one grade and returned to in later grades. For instance, in grade 10, learners are introduced to the topic of equations of motion. With this, learners are introduced to the principles governing motion only in one dimension. This in turn leads to the introduction of Newton's laws of motion in grade 11 which essentially builds on from this. In grade 12, the learners revisit motion and freefall and then are introduced to projectile motion in one dimension and then work done by a force. This is called conceptual progression and coherence. In previous years, this was not the case---this spiral approach towards content was not followed as much. Under the topic of 'vectors', complex concepts such as velocity, force, acceleration, and momentum were all introduced at the beginning of grade 11 in one chapter (Basson and Kriek, 2012).

2.3 Learners' mathematical background for learning physical sciences.

As established, the comprehension of the main physics concepts, principles and laws of physical science, benefits by conceptually linking it to the mathematics involved (Ogunkunle and Obafemi, 2013). For example, when introducing learners to the equations that govern motion in a straight line, learners must be made to see the various symbols in each equation as variables when doing mathematics. Furthermore, these symbols have a particular meaning in science which helps them see the links between the concepts (velocity, acceleration, and time). "Science and mathematics are two closely related systems of knowledge---they are both related to the physical world---science provides concrete samples, while mathematics provides abstract samples" (Kiray,2012: 2). Due to this long-known fact, mathematics is extensively incorporated into both the instruction and practice of science, especially in physics. In practice mathematics is often incorporated in other scientific fields, such as chemistry, biology, geology, and meteorology often, but typically rely less heavily on it than physics does in high school and university level (Ogunkunle and Obafemi, 2013). A few investigations have presumed that the transference of mathematical knowledge or skills into a science course can emphatically influence the students' comprehension of the scientific content (Kiray,2012). In addition, researchers have expressed that utilizing quantitative information during the instruction of scientific concepts prompts a more profound comprehension with respect to the learners (Kiray, 2012). Despite this however, the extensive experience of teaching physics utilizing mathematics from high school level to graduate level and despite years of research on ‘‘problem solving’’ in mhysics, teaching learners to effectively utilize mathematics in physics still eludes the physics community (Redish and Kuo, 2015). Due to this fact, studies done on the matter over the years have confirmed that success in physics, especially in mechanics, is majorly dependent on mathematical conceptual understanding.

Govender (2007), Owolabi (2008), Ighomereho (2005) and Phage et al., (2017) argue that without a solid foundation in mathematics, physical science learners cannot hope to survive in their respective scientific fields. Thanormsuay (2010) also posited that students in science and engineering require a strong mathematical background in-order to succeed in their fields. Study Up (2009) maintained that since many mathematical expressions used in these subjects are learnt exclusively from mathematics, students’ understanding of basic mathematical knowledge greatly influence their ability to cope with top tier content where the application of basic mathematical knowledge is almost mandatory when solving problems in physics.

Akatugba and Wallace (2009) found that issues with mathematics among others were related with students' failure to utilize reasoning in physics. Adegoke (2009) saw that several learners seem to come up short on their thinking capacity associated with the study of physics part of physical science---they have issues with the mathematical activities that are required in physics learning. Study Up (2009) found that even though physical science learners find the subject intriguing, they however, have trouble with the mathematics utilized in the subject. Most students will admit they comprehend the ideas of physics; however, they do not have a clue as to how to substantiate their understanding using mathematics. This concurs with the discoveries of Obafemi (2005), where ninety percent of learners bellyached about the lumbering and thorough nature of physics ideas wherein somebody struggles to tackle a problem without utilizing an equation, practically every one of the themes have a few formulae and somebody must be shrewd not to confuse one formula for another. ‘’Mathematics is an essential element of physics problem solving, but experts often fail to appreciate exactly how they use it. Mathematics may be the language of science, but mathematics-in-physics is a distinct dialect of that language” (Redish, 2005:1). Despite the extensive research done on the learning of both physics and mathematics, the issue of how to successfully incorporate mathematics in physics such in a way that most students succeed in the field persists.

2.4 Approaches to teaching for conceptual understanding of physics concepts at secondary school level and above

There is a plethora of research where the effect of certain teaching strategies on certain Mechanics topics was investigated. These teaching strategies varied on several aspects. They varied in terms of the practices undertaken by the teacher in the classroom during implementation depending on the theoretical/ conceptual framework underpinning these teaching strategies, the resources used, the academic level of the learners/students these strategies are meant to assist and so forth. Some of these studies focused at investigating the effect of learner-centred teaching strategies on the conceptual understanding of physics, neglected to make explicit the required mathematical knowledge. The reader will also note that most of these are international studies and there is little reference made to South African studies around this issue as there is scarcity of such studies. Be that as it may, the studies looked at are in the same context as what the researcher is investigating.

Some studies investigated the effect of teaching strategies on conceptual understanding of Mechanics revolving around active engagement (IE) used the Force Concept Inventory (FCI) and the Force and Motion Conceptual Evaluation (FMCE) as indicators of conceptual understanding of Mechanics (Bernhard,2000; Ornek, 2007; Jackson, Dukerich and Hestenes et al., 2008). The FCI and FMCE assess the conceptual understanding of the force concept, a key concept in mechanics. They were developed to compare the effectiveness of alternative instructional methods in physics (Jackson et al., 2008). Most of these alternative methods such as (IE), modelling, draw from both constructivist and sociocultural views of learning and instruction which stress the crucial role of active engagement of the learner during lessons (Bernhard, 2000). The FCI and the FMCE have become the most widely used and influential instruments for assessing the effectiveness of introductory physics instruction at high school and university level alike and have been cited as producing the most convincing hard evidence of the need to reform traditional physics instruction (Jackson, et al., 2008; Bernhard 2000).

Bernhard (2000) conducted a study to see if methodologies that endeavoured to accomplish high gains in conceptual tests, for example, FCI and FMCE tests for assessment pre-and post-test mediation produce a perpetual conceptual change in students' worldview or if the impacts revealed are just transitory. The data collected indicated that, after active engagement Physics course, students show a decent reasonable understanding of the concepts long after instruction. It is then concluded that some instructional techniques that involve active engagement that draw from constructivist and sociocultural views of learning and teaching do accomplish shifts in students' conceptual framework, eventually resulting in a permanent change of their conceptual understanding.

Ornek (2007) investigated the effects of modelling-based instruction and interactive engagement on students' Physics conceptual understanding at university level. The FCI was used as a pre-and post-test to evaluate students learning and understanding after being exposed to a newly developed approach to teaching Mechanics in an introductory Physics course. Analysis of the results lead to the conclusion that modelling based interactive teaching method helps students to improve their understanding and learning Physics.

Jackson et al. (2008) posits that rather than relying on lectures and textbooks, a modelling instruction program promotes active student development of conceptual and mathematical models in an interactive learning environment. Learners are presented with scenarios to figure out how to model the physical world. Modelling also prepares physics teachers as school specialists on the utilization of technology in teaching science and encourages teacher training in science teaching strategies thus furnishing schools with a significant asset for more extensive reform. The information they gathered on certain students utilizing the FCI as pre- and post-test to assess learning for the individuals who have been exposed to the modelling program regularly indicated that achievement was much higher on a standard test of conceptual understanding as compared to learners who were taught conventionally. Furthermore, the modelling strategy is effective with students who have not generally done well in physics. Experienced modelers report increased registration in physics classes, parental fulfilment, and improved accomplishment in school courses across the curriculum.

Qhobela and Moru (2011) studied the effect of, and challenges with, empowering argumentation on learners' conceptual development in physics. The theoretical framework came from two socio-cultural points of view of learning: learning science occurs in a social setting, and it is a desultory and social procedure. Thus, a triple-stage teaching strategy planned to support argumentation was actualized at a secondary school in Maseru in 2009. Information was gathered through sound taping of interviews and learners' composed reports. Analysis of results indicated that the presentation of argumentation as a technique of introducing learner-centred methodologies in classrooms demonstrated to be beneficial for the learner's conceptual improvement. However, the challenges of practicing argumentation included the utilization of second language and acculturation of learners into a scientific network. From the study, the participants--learners did some portion of their dialogs in Sesotho, their first language, rather than english the second language which is utilized as the language of teaching. Learners also utilized short sentences that required elaboration and rarely addressed each other's justifications.

Ogunkunle and Obafemi (2013) explored the impact of mathematical capabilities of learners on their performance in Physics on the topic of Sound Waves. The study was a quasi-experimental pre-test post-test involving three experimental groups and one control group where each group was thought with a different instructional strategy. A Mathematics Ability Test (MAT) and Physics Performance Test on Sound Waves (PPTSW) with reliability coefficients of 0.97 and 0.85 respectively were utilized as data collection tools. Analysis of results indicated a critical contrast in the impact of Mathematics capacities of learners on their performance in sound waves. Likewise, there was a clear distinction in the impact instructional strategies on the performance of the learners in sound waves. The post hoc analysis indicated that the critical distinction in the mathematics capacities was acknowledged to learners for high mathematics capabilities while Guided-Discovery strategy represented the huge contrast found in instructional methods. The researchers suggested that a sound mathematics background should be ensured for physics learners to enhance their performance in physics concepts and that interactive and practical-oriented instructional methods like Guided-discovery and Demonstration methods should be preferably used in teaching of physics concepts.

Iwuanyanwu and Ogunniyi (2019) conducted a quasi-experimental design case study where first year pre-service science student teachers formed two groups: a control and an experimental. The control was exposed to traditional teaching strategies while the experimental group was exposed to problem solving skills using a Dialogical Argumentation Instructional Model (DAIM). An analysis of the data derived from the participants' responses to a Physical Science Achievement Test showed the experimental group greatly outperformed their control group on problem solving in classical mechanics.

Djudin (2020) conducted a study where a quasi-experimental method was employed to investigate the degree of effectiveness of integrating metacognitive strategies with transfer of learning of mathematical knowledge in solving physics problems of sound waves on pre-service teachers. Analysis of results proved the model to be effective in enhancing the students' physics problem solving competencies and improving pre-requisite mathematical knowledge and skills.

Computational Technology and its impact on learners' understanding of certain physics topics to improve learning and teaching has also been investigated over the years. Adeyemo (2010) explored the effect of information and communication technology where 157 physics learners and 2 physics teachers were taken as participants. The information gathered were broken down and discoveries made from the data showed that ICT has an incredible effect on the teaching and learning of physics and makes learning of physics so intriguing for the learners. Graphs can also be utilized to incite the re-examination of the role technology plays in science teaching and learning (Edwards, Petersen, Andrus, Dudeck and Horan, 2008 et al., 2008). Some product items are explicitly intended to make graphs simple and easy to comprehend (Lymer, 2003). Phage (2015) stated that using a personal computer as an instructional tool and as an examination device can probe student thinking. One can visualize most experimental observations and data on a computer.

In an investigation by Araujo et al. (2008) to research the adequacy of computational simulations in understanding kinematics diagrams, an experimental group was exposed to correlative computational exercises while just conventional encouraging techniques were utilized on the control group. Analysis of results indicated that the performance of learners in the experimental group displayed a statistically significant improvement as opposed to the learners in the control group. sonic range finders and graphing calculators were shown to be just as useful in the understanding of graphs (Palmquist, 2001). They can assist students when it comes to the comprehension of graphs of motion. Sonic range discoverers and graphing calculators are likewise said to be anything but difficult to use when analysing motion, since learners can picture the movement and can examine the graphs that speak to the motion observed (Phage, 2015).

2.5 The use of mathematics where physics, particularly, mechanics is concerned – a complex problem for learners and students.

As established from the previous sections, some studies have also recognized that even at university level, students struggle with making proper links between mechanics concepts and the underpinning mathematics ergo failing to recognize the links between observed motion and algebraic formalism (Govender, 2007). Students and learners make little connection between the algebraic symbols of the formula and the features of a physical system – contrary to a physicist, who readily notices the utilization of formulae in real life circumstances (Govender, 2007). Reddish (2005) argues although mathematics is commonly referred to as the “language of science”, that does not necessarily mean that students can transfer what they learn in the mathematics classroom to the physics classroom independently. “Physicists tend to blend conceptual physics with mathematical symbolism in a way that profoundly affects the way equations are used and interpreted” (Redish, 2005:1).

The objective of using mathematics in a science classroom (particularly in physics) is different from that of using mathematics in the mathematics classroom and learners do not realize this. In physics, the objective is to use mathematics in a way that represents meaning about physical systems rather than abstract relationships (Redish and Kuo, 2015). The semiotics differ---the way meaning is put into symbols is different for physics compared to mathematics (Redish, 2005). For instance, at secondary level, an example would be the use of bold face signs such as +, - and =. These signs, for example, are used in vector equations in some textbooks to emphasize the difference between vector and scalar operations with ordinary numbers. Most of high school level physics problems are dealt in one-dimensional physical systems, where vectors are simply assigned positive and negative signs. However, leaners end up perceiving no practical difference between scalar and vector algebra because their knowledge about vector-scalar symbolism is limited (Govender, 2007). Vector-scalar symbolism becomes imperative because if learners do not distinguish between scalar and vector quantities, they will be unable to make the distinction when solving physics problems (Govender, 2007). At secondary level, the South African mathematical syllabus does not discuss the topic of vectors, it is only discussed in the physical science syllabus.

This has profound implications on how learners are taught mathematics and science and how they are taught to use mathematics in science at high secondary level which ultimately affects the learning process. Involving learners during the teaching and the learning processes making sure they see the connections between the two fields motivates them and increases achievement in both science and mathematics (Furner and Kumar, 2007). This speaks to the constructivist approach towards teaching and learning. Some studies conclude that transferring mathematical content or skills into a science course has a positive impact on the students' and learners' understanding (Kiray, 2012). Additionally, many researchers have stated that using mathematical quantitative knowledge when explaining scientific concepts results in a more profound understanding where learners and students are concerned (Kiray, 2012).

2.6 Theoretical Framework

Constructivism posits that all newly constructed knowledge is built on pre-existing knowledge and experiences (Bay, Bagceci and Cetin., 2012). ''Meaningful learning involves the active creation and modification of knowledge structures, instead of learners' passive absorption of information" (Phage, 2015:25). Thus, constructivism is recognized as a process where learners use their pre-existing knowledge, beliefs, interests, and goals to makes sense of incoming new information, which in turn may result in the modification of their pre-existing ideas (Haney, Lumpe and Czerniak, 2003). In this way learning proceeds as every individual 's conceptual schemes are progressively reconstructed as they become exposed to new experiences and ideas (Phage, 2015).

Constructivism, together with conceptual change, is regarded as the foundation for the recent/modern views of science and science education. Scientific uncertainty, learner negotiation, shared control, critical voice, and personal relevance are all considered to be components of this tenet (Haney, et al., 2003). In short constructivism puts emphasis on the social context, culture, and collaborative side of learning.

2.6.1 Social Constructivism as a Learning Theory

The provenance of constructivism is owed to Vygotsky's ideas of how the processes of teaching and learning occur. Vygotsky directed most of his attention towards the effects of social interaction, language, and culture on the learning process. According to him, the source of metacognitive processes is related to the culture. A child can only develop his/ her learning potential develops only if s/he "other knowledgeable individuals" are present (Bay, et al., 2012). "When we are with others, we can succeed much more than when we are alone" (Bay, et al., 2012). This is what is called social constructivism.

Azzarito and Ennis (2003) posit that as per the social constructivist teaching theory, the classroom seen as a scholarly society, the learning procedure occurs by methods for peer cooperation (collaborative approach towards learning), student responsibility for educational programs and instructive encounters that are authentic to the learners." Equally important in this regard are the opportunities created through problem solving to share with peers, clear doubts, reflect and even change one's view in the face of more convincing arguments" (Iwuanyanwu and Ogunniyi, 2019:492). Learning occurs primarily through interactions with peers, teachers, and parents, while teachers facilitate and stimulate conversation by harnessing the natural flow of conversation in the classroom (Davis, Witcraft, Baird, and Smits, 2017). According to social constructivism, successful teaching depends on interpersonal interaction and discussion, while focusing on the learners' understanding of what is being discussed (Davis et al., 2017). Thus, in a social constructivist learning setting, because the educator's role is more guide than all-knowing, learners inevitably procure and improve top-level abilities like research skills, critical thinking and problem solving (Phage, 2015). Teacher-centred methodologies in comparison are said to only guide learners to retain information and fail in improving the learners' basic critical thinking and problem-solving abilities (Bay, et al., 2012). Records show that learners who have been given this sort of instruction are progressively successful in the real world, they are not overwhelmed by real life troubles, and they continue to create quality life standards for themselves (Bay, et al., 2012).

There are studies in literature investigating the effects of constructivist teaching approaches to learners' problem solving and conceptual understanding. In these studies, constructivist approach-based learning environments for experimental groups and traditional approach-based learning environments for control groups were created. At the end of the processes, problem solving skills, attitudes towards lessons and the change in metacognitive levels of the learners in the experimental groups were determined to be higher and more significant than of the ones in the control groups.

One of the teaching strategies under the collaborative approach towards learning is the group approach whose effectiveness was investigated by Dlamini and Mogari (2013). They examined the effects of a group approach versus a non-group approach on the mathematics performance of the learners. They described the group approach as an environment where learners are allowed to collectively sit together, discuss and solve tasks (Dlamini and Mogari, 2013). The study's findings revealed that learners taught using a group approach to learning performed significantly better than learners taught using a non-group approach (Dlamini and Mogari, 2013).

Worksheets and tutorials issued should guide learners during lessons, to work collaboratively in small groups, so that they may acquire the required qualitative reasoning for the development and application of important physics concepts and principles (Phage, 2015). For example, being in learning environments that allow for peer learning, have been found to facilitate the construction of knowledge and overcome deficiencies in the interpretation of kinematics graphs (Phage, 2015).

2.6.2 Constructivist learner-centred teaching strategy for the study

Instead of knowledge being solely transmitted from teacher to learner, learners should also be taught to construct knowledge themselves (Haney et. al., 2003). An interactive social environment between teachers and learners and amongst the learners themselves should be created (Phage,2015). Bay et al., (2012) posits that the learning process should be viewed as an adaptive process. When teaching and learning physics, the teacher should focus on what learners already know, either from experiences from their everyday lives or from the previous classroom and focus on helping learners build on existing knowledge so that may incorporate the new information. “They should therefore be encouraged to develop cognitive skills of learning through experience, that is, to make sense of meaningful reception learning through experience and integration of concepts” (Phage, 2015:36).

There are several studies where the effect of various constructive teaching and learning strategies on learner conceptual understanding of mechanics were investigated as seen from the previous sections but for the sake of the hypotheses of this study the teaching strategy that whose effect will be investigated must include the following components:(a) It must be one that ensures learners are active and work collaboratively (group approach) with one another in the classroom during lessons which has been alluded to from the previous section and (b) most importantly it must place emphasis on the mathematical knowledge that underpins the physics concepts governing equations of motion. Such a teaching strategy may be derived from practices of social constructivism where learners work together cooperatively (group approach) as mentioned from the previous section and a model that aims to enhance scientific conceptual understanding by using the required mathematical knowledge and skills. This can be derived from Kiray's balance model of integrating mathematics and science.

Although Kıray's (2012) development of an instructional program for the integrated science and mathematics argues that integrating science and mathematics may not always be feasible, it does suggests how the content knowledge of science and mathematics can be organized, and the related objectives can be identified. Based on these suggestions, a balanced model that aims to integrate science and mathematics was developed. Central to this model is the content knowledge (science and mathematics) accompanied with skills, the process of teaching and learning, affective characteristics and measurement and assessment as seen in Figure 6 below.

However, it is essential to maintain a balance between science and mathematics in this model, as it is intended to design a long-term curriculum. If a curriculum is designed for one year, the integrated curriculum should not favor science over mathematics. It is important to give equal time to both disciplines in the process of achieving balance.

The model has several different dimensions, however depending on one's objectives, it is possible to focus on all dimensions of the model or simply focus on some (Kiray, 2012). For the sake of the hypotheses of the study the focus will be on the Content knowledge: Science-centered Mathematics-Assisted Integration (SCMAI) and the Processes of Teaching and Learning dimensions of the model. These two dimensions of the model mentioned allowed the researcher to centre the study on its aims and objectives.

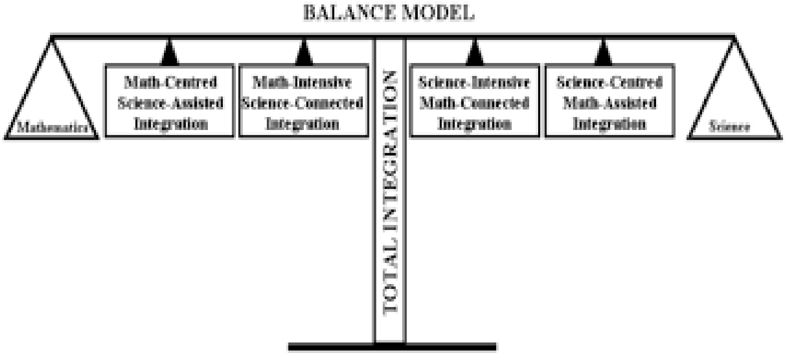


Figure 6: Content knowledge for the balance model (Kiray,2012)

At the Content Knowledge SCMAI dimension of the model--mathematics is positioned as an interval discipline, and the outcomes of science courses are categorized as foundational. It is possible to integrate science and mathematics by integrating topics to make it easier for learners to transfer themes autonomously. Mathematical content is transferred at the appropriate points during the science course to reinforce outcomes and it is highly suggested that themathematical content to be used for integration be taken from the mathematics curriculum.

The Process of Teaching and Learning dimension of the model draws its design from the standards of constructivism.The integrated scientific and mathematical curriculum views the mathematics course as an experimental or quasi-experimental discipline, similarly to the science course, in which the process of discovering, finding, and experimenting are also used for collecting information. In both courses, the same instructional methods, techniques, and strategies must be used. The design of the teaching-learning process is based on the view that the teaching-learning process in the science course affects that of the mathematics course, and vice versa. The assumption of the balance model is in accordance with the views presented in the relevant research.

Teaching methods, techniques, and strategies are selected based on whether content and skills will be transferred from the other course or if they will be fully integrated. Either way, in an integrated science and mathematics syllabus, a teaching-learning process that is suited to the constructivist approach and in which learners/students are active participants in the process can be utlised since the mathematics course, like the science course, allows for the adoption of a constructivist approach to teaching, (Kiray, 2012).

Summary

Mathematics is an important part of science, particularly physics, which relies heavily on math (Kiray, 2012; Phage, 2015). Ogunkunle and Obafemi (2013) argue that mathematical skills should be developed at an early age, where teaching is concerned. Physics teachers should recognise the need to engage learners with pre-requisite mathematics concepts in physics before engaging them in real physics as this will allow for meaningful understanding and integration of mathematics concepts naturally embedded in physics (Apata, 2019). Because of this, authors such as Davison; Miller and Metheny (1995), Berlin and White (1992), Lederman and Niess (1997, 1998), Roebuck and Warden (1998) and Huntly (1999), Lehman (1994), Frykholm and Glasson (2005) and Furner and Kumar (2007)) also believed that there is optimism for improving science teaching and student achievement through the integration of science and mathematics. "Yes, we should integrate mathematics and science wherever it is possible in the curriculum" (Furner and Kumar, 2007, p.188). As science, especially physical science involves mathematics, and both subjects involve process skills, they concluded that integrating science and mathematics methods courses might be a way to improve science education.

However, despite the plethora of research around the subject of learning of both physics and mathematics, the problem of how to effectively integrate mathematics in physics in a way that most learners and students fully understand remains a mystery (Reddish, 2015). Although the interaction between mathematics and science has long been recognized, teachers still struggle in properly teaching this close relationship under the current curriculum. One of the causes of this is the fact that there is a deficiency of the much-required SMK and PCK which is a barrier to the successful integration of science and mathematics. As mentioned from the previous sections successful integration can only occur if teachers possess adequate SMK and PCK for both science and mathematics.

Another would be the centralised and discipline-centred curriculum that persists. Teachers must limit themselves to the science course or the mathematics course due to the demands of the current curricula. Due to this, they may feel that they are incapable of teaching the other course. In the balance model, this fact is considered, and a variety of integration options are available to teachers. For instance, using the SCMAI, which can be regarded as a simple version of an integrated curriculum, may improve teachers' self-efficacy, and help them learn to successfully integrate mathematics into science in a way that reaches most learners and students.

From the review of related literature, it can be also concluded that the way learner/students are taught mathematics and physical science/physics and how they are taught to use mathematics in science has profound implications as to how they understand physics concepts. There is more to problem solving than learning the facts and the rules. What experts do when they solve simple problems is a bit more complex than it may appear to them and is not "just" what is learned (or not learned) in a mathematics class (Redish, 2005:10). Teaching students to learn to recognize what tools and skills best fit certain circumstances remains crucial. Science, particularly, physical science/physics is a good place for science educators and scientists to learn how to apply mathematics to science. However, if too much emphasis is placed on misguided techniques and methodologies when students and learners are taught these scientific concepts, it may hinder them from learning other important parts of how to approach problem solving when they need to use their knowledge of those concepts and relevant equations (Redish and Kuo, 2015). Science educators and scientists also need to improve their understanding of the cognitive processes involved in physics problem solving and find activities that help our students/learners build knowledge into intuitions/understanding (Redish, 2005). This speaks to the social constructivist way of teaching and learning science.

Nowadays, learners are required to apply or relate what they learn in class to what is happening in their daily lives, environment, communities and more. A constructed knowledge base is crucial if they are to understand what is happening in their society in terms of culture and context. In-order for learning to be meaningful, science educators should create learning environments that allow involvement of learners in social activities. Unfortunately, students and learners often find themselves in traditional teacher-centred environments where the educator just relays all the information (Yackel et., 1991). "The disadvantage is that learners are not actively involved in the abstraction and generalization process, which entails inductive thinking and reasoning. Because learners lack qualitative reasoning, which is the skill that ultimately enables learners to apply concepts" (Phage, 2015,p. 27).

The students/learners just listen to the educator and take notes from the board without any active participation or involvement (Dlamini and Mogari, 2013). Instead, teaching should be learner–centred so that learners can ask questions, engage with one another, and be engaged by the educator during lessons.

Chapter 3

RESEARCH METHODOLOGY

3.1 Introduction

The purpose of the study was to establish the relation between grade 10 learners' mathematical competency and their understanding of equations of motion in physical sciences. The purpose of this chapter is to describe the research design and methods employed to conduct this study. This chapter describes the sampling, data collection instruments and procedures, data analysis and the role of the researcher in the mixed methods research conducted. Lastly, the chapter discusses how the mixed method approach met the requirements of this study as well as its validity and reliability. The researcher elected to utilize a mixed method approach as he believed that to solely focus on the quantitative aspect, would be inadequate, where data collection is concerned---the qualitative aspect was just as essential. The researcher sought not only to gather empirical, statistical data and analysis but also the in-depth understanding of it and its implications where the humane and social aspect are concerned. Hence a mixed-method approach was adopted for the study, where the quantitative aspect having been given higher priority. It was the researcher's belief that a mixed methods study would give him a more comprehensive view of this narrowed down and focused topic. The aim of the study was to inquire about a phenomenon (importance of mathematics in solving problems in equations of motion in grade 10 physical science) whose setting is within a real-world context. This setting for the study can be described as an educational classroom setting, where an already existing group of learners were participants for the study were used for data collection purposes. These classrooms were located around the city of Cape Town at schools in close proximity to where the researcher was based.

3.2 Research design

As a rule, research is conducted to explain the relationship between the independent and dependent variables, and the design of the research is to structure the investigation in that manner. The researcher identifies and controls independent variables that can help explain the observed variation in the dependent variable, which reduces error variance (unexplained variation). This method of control is called experimental control because the research design is structured before the research begins. Research design is the science (and art) of planning procedures for conducting studies so as to obtain the most accurate results. Research design involves specifying how evidence will be collected and how it will be interpreted. The types of research designs include experiments, quasi-experiments, double-blind procedures, and correlated groups (Thomas, 2020).

In real-life situations such as educational settings, randomization and having complete control of every variable present is almost impossible because real-life situations are complex natural settings (Ponce and Maldonado, 2014; Thomas, 2020). Thus, adopting a true experimental research design for the quantitative aspect of the study was not possible. However, the same could not be said for quasi-experimental designs, as these designs usually become the next choice when randomization is not possible.

Quasi-experimental methodologies are often conducted to evaluate the effectiveness of a treatment--perhaps a type of psychotherapy or an educational intervention. One of the most common ones is the non-equivalent pre-test and post-test design. In the pre-test-post-test non-equivalent groups design there is a treatment group that is given a pre-test, receives a treatment, and then is given a post-test. But at the same time there is a non-equivalent control group that is given a pre-test, does not receive the treatment, and then is given a post-test.

In typical experimental designs with random assignment, the control and treatment groups are considered equivalent in every way other than the treatment. But in a quasi-experiment where the groups are not random, they may differ in other ways—they are non-equivalent groups (Thomas, 2020). When using this kind of design, researchers try to account for any confounding variables by controlling for them in their analysis or by choosing groups that are as similar as possible (Thomas, 2020).

There were two non-equivalent, non-randomized groups: a treatment group that was given a pre-test, receive a treatment and then given a post-test while at the same there is a control group that will be given a pre-test, were exposed to traditional teaching approaches on the topic and followed by the administration of the post-test. The main design for quantitative data collection is shown in figure 2. Thus, the researcher dubbed this as the non-randomized, non-equivalent pre-test and post-test control group quasi-experimental research design. The question, then, was not simply whether participants who receive the treatment improve, but whether they improve more than participants who do not receive the treatment. when the post-test results for the two groups were analysed using statistical methodologies. The nature of this improvement was be given special attention as well.

The study proceeded in two phases: an initial quantitative instrument phase, followed by a qualitative data collection phase, in which the qualitative phase builds directly on the results from the quantitative phase. The quantitative data collected, and analysis was given higher priority, as the focus was the impact of the treatment/intervention, making the analysis a quantitative-dominant mixed analysis. However, the researcher believed that the inclusion of qualitative data and analysis was likely to increase understanding of the underlying phenomenon. Thus, ultimately the research approach followed was a pre-test and post-test non-randomized non-equivalent quasi-experimental mixed-method approach for this study, where the data collected for analysis was quantitative and qualitative in nature.

3.3 Sampling of participants

The researcher selected the groups from two grade 10 classes two different schools (more details about the schools will be provided in the next section) to avoid contamination between the two groups. Certain steps were taken, however, to ensure that the experimental and control groups are characteristically as similar as possible, because in experimental research, the different groups must be equated on all extraneous and confounding variables that may have an effect on the dependent variable before the different treatments are administered (Dlamini and Mogari, 2013; Thomas, 2020).The researcher ensured that the groups are made up of learners with comparable physical science test scores and are of the same age group. Taking such steps was an endeavour to minimize the threats to the internal validity of the study because the researcher wanted to eliminate some of the most important confounding and extraneous variables (Thomas, 2020). The research design was in question in terms of its internal validity to some extent, though not as much if the study had followed a non-experimental design, since the researcher was essentially utilising a convenience or intact sample, which were grade 10 physical sciences classes in an educational classroom, a social setting. This is because quasi-experimental designs often involve real-world interventions instead of artificial settings such as a laboratory. However, it’s external validity was not in question as quasi-experiments often have higher external validity since they can use real-world interventions instead of artificial laboratory settings (Thomas, 2020).

From the proposal, the researcher considered a convenient or intact sample (N = 100) of grade 10 physical science from two secondary schools. However, because of the COVID-19 crisis, the groups had to be a little smaller, 18 learners from the experimental and 18 from the control groups (N = 36). The reason for the use of a convenience sample was simply because randomization was impossible due to factors such as syllabi constraints, schools’ timetable. Criteria-wise, the two schools were chosen based on their poor grade 12 performance the year before the study. Ethical clearance for the study was obtained through the institution’s ethics committee, the Department of Basic Education in the Western Cape, and the schools’ principals and teachers were involved in-order to obtain the learners consent to participate in the study. Seeing that most learners are under parental care and younger than 18, permission was also sought from their parents and legal guardians. Furthermore, all participating learners gave informed consent that allowed the researcher to use the generated data.

3.4. Research Site and Population

The study took place in two public high schools (one control and one experimental) around the city of Cape Town. One of the main reasons for the selection of schools in Cape Town is due to financial constraints and time constraints. Financially, the researcher is funding his own studies and does not have the financial means to expand the study to schools outside the province. Time constraints have to do with the fact that the researcher has a limited timeframe in which he must complete his studies.

Cape Town is also one of the biggest cities in the country with several underperforming underprivileged schools, thus it was relatively easy to get a convenience sample, inexpensive, proximity and participants are readily available. The two schools were chosen based on their poor grade 12 performance the year before the study. The reason for selecting such underperforming schools is because they make up a substantial amount of the schools in the country. The learners at these two specific schools are exposed to the same curriculum and the same conventional teaching style**.** These types of schools are also known for having limited resources. Teacher and textbooks are the only resources the learners have at their disposal. This allowed the investigation to fully focus on the variables the study meant to investigate as extra learning resources, like technology were also automatically eliminated.

Finally, in order to avoid contact between the two groups, the two schools chosen had to be at least 80 kilometres apart. According to Dlamini and Mogari (2013), such separation effectively eliminates the possibility of diffusion, contamination, rivalry, and demoralization.

3.5 Data Collection

3.5.1 Quantitative Methodology

Pre-tests and Post-tests

In behavioural research, pre-test-post-test designs are widely used, primarily for the purpose of comparing groups and/or measuring change resulting from experimental treatments (Dimitrov and Rumrill, 2003). This is usually done by essentially comparing groups with pre-test and post-test data and related reliability issues (Ponce and Maldonado, 2014).

For this study pre- and post-test data collection was done by way of a standardized grade 10 Equations of Motion Achievement Test (EoMAT) and Mathematics Ability test (MAT) (Addenda A and B). Test items for both instruments were be generated by the researcher himself as test items from previous grade 10 examination question papers have proven to be untrustworthy. The EoMAT was used to measure the performance of learners with respect to conceptual understanding, application, and analysis. The MAT was used to measure the learners' mathematical ability. The MAT contained a series of questions mathematics questions based on the mathematical concepts and skills required by the learners to understand and solve problems on Equations of Motion.

The choice of physics topic investigated was motivated by the perceived difficulty of the topic for grade 10 science learners. If instruction is poor and inadequate on these topics in grade 10, the problem persists on related topics throughout the FET phase (grades 10-12) as shown in the NSC Physical Science National Diagnostic reports and TIMSS in recent years. Furthermore, it was assumed that because the topic presented tasks that combined mathematics and science, as there are plenty of mathematical calculations involved when solving problems, this would be most inspiring for the experimental group.

The EoMAT and MAT were developed through iterative processes of acquiring test items from classroom teachers and state-approved textbooks, receiving feedback from subject specialists and advisers, and repeating content validity assessments. Local subject specialists were enlisted to assist in revising test items to ensure they are relevant to learners' real-world situations. It was also necessary to calculate the difficulty and discrimination indices of EoMAT and MAT items.

The validity of the achievement and ability tests (EoMAT and MAT) was determined by an expert panel in science and mathematics education and research who evaluated the tests' suitability for the purpose of the study. The panel provided insightful feedback and validity ratings for the test items, which were used to determine and improve the content validity of the tests for the study. Because the test items in each test were of varying difficulty, the Richardson-Kuder 20 formula was used to determine the internal consistency of the EoMAT and MAT.

The Kuder-Richardson 20 formula

$$\rho_{KR20} = \frac{k}{k-1}\left(1 - \frac{\sum_{j=1}^{k} p_j q_j}{\sigma^2}\right)$$

Where:

k = number of questions

p_j = number of people in the sample who answered question j correctly

q_j = number of people in the sample who did not answer question j correctly

σ_2 = variance of the total scores of all the people taking the test = VARP(R1) where R1 = array containing the total scores of all the people taking the test.

The formula was used to find reliability index values that indicated whether the tests can produce similar results on repeated use. For the EoMAT and MAT, reliability coefficients of 0.82 and 0.90 were obtained respectively. Such high values suggested internal consistency of the tests as test items within the 0.80 to 0.85 range are preferred.

The total score for the EoMAT and MAT was 70 and 50, respectively. Both the EoMAT and the MAT were used as pre-tests. The pre-tests determined the learners' initial performance level prior to the four-week intervention. Only the EoMAT was administered as a post-test at the conclusion of the 4-week intervention to compare the effects of the collaborative approach (group approach) teaching strategy that accentuates the mathematics required for conceptual understanding of equations of motion (experimental group) and teachers' conventional teaching (control group) on learner performance. Learners in the experimental school were classified as having low (less than 20), average (between 20 and 35), or high (above 35) mathematical ability based on their MAT achievement pre-test scores (ADDENDUM C).

3.5.2 Intervention Procedure

The researcher adapted the intervention procedure from Dlamini and Mogari (2013) who examined the effectiveness of a collaborative approach (group approach) in learning mathematics in a similar study. During the intervention procedure, the researcher played the role of teacher.

There were two types of lesson plans developed for this study: traditional lesson plans for the control group, and constructivist lesson plans for the experimental groups that aim to make explicit the mathematics behind a grade 10 mechanics topic, namely equations of motion. These lessons were planned by the teacher, who is also the researcher, and they included the required science content and worksheets, however the lesson plans for the treatment group also included the mathematics needed to understand the science content (Addendum D).

During the lessons, the learners were given worksheets that contained equations of motion problems in which they were required to solve problems. Those in the control group were only taught the topics in a conventional, traditional manner with only the science being taught without any emphasis on the underlying mathematics. The experimental group was taught in a way that uses ideas from social constructivism through a collaborative (group-approach) learner approach and makes explicit the mathematics needed to enhance the understanding of equations of motion. Both groups were observed over a period of 4 weeks, conducting the lessons for 4 hours a week and where each lesson was about 50 minutes long a day.

In the experimental school, the researcher established a learning setting conducive to collaborative learning, shifting the role of the instructor and learner in the science classroom completely. The learning environment made it possible for learners to work together and collaborate on their tasks with one another (Phage, 2015). Dlamini and Mogari (2013) talk about social standards that describe viable collaborations within the classroom. These social standards are common classroom standards such as working in groups when tackling a problem and working tirelessly as a group toward a solution when the problem is challenging (Dlamini and Mogari, 2013). To foster social norms for effective group discussions for the experimental school, the researcher facilitated interaction among learners by arranging desks in groups of five to seven participants, as suggested by Yackel et al., (1993).

Each group within the experimental school was made up of learners with varying levels of mathematical ability and achievement, implying varying levels of cognitive ability based on MAT pre-test scores. Each group's participants were encouraged to explain their problem-solving approaches and consider alternative explanations from other learners. Rather than simply accepting the solutions of other learners, they challenged them and offered alternatives. They were also encouraged to use the solution activities of their fellow group members as prompts to develop group solutions. Learners were encouraged in the experimental school to be prepared and ready to share their problem-solving knowledge with their peers, to listen attentively when their peers presented their problem-solving knowledge, and to support one another. In each group, the researcher selected a leader, an explainer, and a recorder. Explanations and solutions were only provided when the teacher was required to do so.

Furthermore, in the experimental group, the several problem examples in equations of motion that were given to the groups in worksheets enabled more robust interaction between the learners. Worksheet tasks were identical in both the experimental and control schools. In comparison however, the experimental group received more exposure to the mathematics underpinning the physics than the control group. To ensure learners understood the tasks assigned to them and adhered to the roles the researcher assigned to them, the researcher walked from group to group, monitoring the situation. Further, the researcher sought to determine whether the group learning dynamics of listening, writing, answering, questioning, and critically assessing contributions were taking place. As a teacher, walking and circulating amongst groups encourages learners to be more engaged, resulting in more fruitful discussions (Dlamini and Mogari, 2013).

The researcher encouraged learners to work independently and to apply some of the concepts they discussed in groups when completing new tasks. They were told to ask for help from the group only when they ran into serious problems. The researcher asked the participants questions such as "What do you think about what your fellow group member said? ", "Do you agree with your fellow group member? ", and "Do you think you can learn from other learners? " While they were interacting in groups. Answers to these questions were considered as a reflection of what learners thought about a collaborative approach to learning science. The EoMAT post-test was administered on the final day to both the experimental group and the control group in order to compare the effects of the various teaching strategies on learner achievement. There were exactly the same questions on the post-test as on the pre-test.

3.5.3 Qualitative Methodology

Classroom observation

The researcher immersed himself in the setting where the participants were and kept a keen eye on the participants as he was taking down notes. Observations like these are accepted when a researcher goes on-site to a location so that he/she can directly observe the participants' behaviour. This takes place in the natural environment of the participating groups. Thus, the researcher paid close attention to_classroom practices and norms of classroom interactions and made sure that teaching in the experimental and control groups followed the models of learner-centredness and teacher-centredness, respectively. Using the descriptions presented from the previous chapters, teaching in a way that accentuates the mathematical knowledge needed to enhance the understanding of science in conjunction with ideas of social constructivism where are allowed learners to actively participate during the lessons and can work collaboratively in groups is considered as a learner-centred approach and the conventional instructional approach is considered as a teacher-centred approach.

Focus group interviews.

Five learners (*N* = 8) from the experimental group were purposively selected for semi-structured interviews to provide their opinions on the teaching style they received in their respective group (section 4.5). The following sampling criteria were established to select learners from the experimental group for interviews:

- Performances of learners in post-test (all performance categories were represented: low, medium, and high). Learners were classified as low-performing (less than 28), average-performing (between 28 and 49), and high-performing (above 49) based on their EoMAT scores.
- Level of involvement during lessons (learners who participated minimally or maximally were equally selected)

The interviews were designed to provide the researcher with first-hand, in-depth primary data from learners. The semi-structured interviews were not only prepared for the research as a discussion guide ahead of time to guide the conversation, but also to allow flexibility in the interviews to go off-script. This allowed for a balance between the structure of standardized questions, while the interviewees took the interviews beyond the discussion guide Due to time constraints, the participants selected from the experimental groups were utilised as focus groups. The interviews were audio-taped and then transcribed for analysis. According to Maree (2021), the use of mechanical recordings during data collection, such as audio recordings of focus interviews, increases the trustworthiness of the study because the data can be stored, and independent researchers can attempt to duplicate the study independently. To improve the likelihood that the research findings and interpretations will be deemed trustworthy, qualitative researchers frequently use separate data gathering methods --- interviews, classroom observations, (Nowell et al., 2017).

3.6 Data analysis

A mixed method approach was used to collect and analysed the data for the study. The first phase saw the collection of quantitative data and then analysed. This was followed by the second phase of qualitative data collection and analysis. Below I provide details about the different approaches used to analyse the data.

3.6.1 Quantitative data analysis

Pearson product-moment correlation

As suggested by the main research question, the aim of this study was to establish the relation between grade 10 learners' mathematical competency and their understanding of equations of motion in physical sciences. The first research question and hypothesis which focused on the relation between mathematical understanding and performance in equations of motions were investigated using the Pearson product-moment on the EoMAT and MAT pre-test scores to see if there is a correlation between the two. The strength of a linear relationship between different variables is measured by the Pearson product-moment correlation coefficient, sometimes known as the Pearson correlation coefficient, which is indicated by the symbol r. The Pearson correlation coefficient, r, shows how far all these data points are from this line of best fit (i.e., how well the data points match this new model/line of best fit). Basically, a Pearson product-moment correlation seeks to draw a line of best fit through the data of two variables.

The bivariate Pearson Correlation yields a sample correlation coefficient, abbreviated as r, that assesses the strength and direction of linear correlations between groups of continuous variables. The Pearson Correlation, in turn, assesses if there is statistical evidence for a linear relationship among the same pairs of variables in the population, represented by a population correlation coefficient, ρ ("rho"). This measure is also known as: Pearson's correlation or Pearson product-moment correlation (PPMC)

The Pearson correlation coefficient, r, can range from +1 to -1 like all bivariate correlation analyses. There is no link between the two variables, as indicated by a value of 0. Positive associations have values greater than 0, meaning that if one variable's value rises, so does the value of the other. A result that is less than 0 denotes a negative connection, meaning that when one variable's value rises, the value of the other variable decreases.

The Pearson correlation coefficient, or r, will be closer to +1 or -1, depending on whether there is a positive or negative link between the two variables, the stronger their association. When you reach a value of +1 or -1, all of the data points are on the line of best fit; no data points deviate from this line in any manner. Variation is present around the line of best fit when r is between +1 and -1 (for instance, r = 0.8 or -0.4). The variation around the line of greatest fit increases with the r value's proximity to 0. The following recommendations have been made for interpreting Pearson's correlation coefficient:

Coefficient, r

Strength of Association	Positive	Negative
Small	.1 to .3	-0.1 to -0.3
Medium	.3 to .5	-0.3 to -0.5
Large	.5 to 1.0	-0.5 to -1.0

Before using Pearson's correlation to analyse data, the first and most crucial step is to determine whether it is permissible to do so. Since there are four assumptions that support Pearson's correlation, one's study design and data must "pass/meet" these assumptions in order for conclusions drawn to be legitimate and reliable. Because the data "violates/does not meet" one or more of these assumptions, Pearson's correlation will frequently be the improper statistical test to perform. Working with real-world data, which is frequently "messy," as opposed to textbook examples, is not unusual. There is usually a workaround, whether it's switching to a different statistical test or modifying one's data so that Pearson's correlation may still be used. The following are the four stated assumptions.

Assumption #1: The two variables should be measured on a continuous scale (i.e., they are measured at the interval or ratio level) like the pre-test EoMAT and MAT scores for this study (measured from 0 to 100).

Assumption #2: The relationship between two continuous variables should be linear. Simply put ones ' two variables on a graph (a scatterplot, for example) and look at the shape of the graph to see if there is a linear relationship between them. A linear relationship was seen after creating a scatter plot (figure 7) using the EoMAT and MAT pre-test scores.

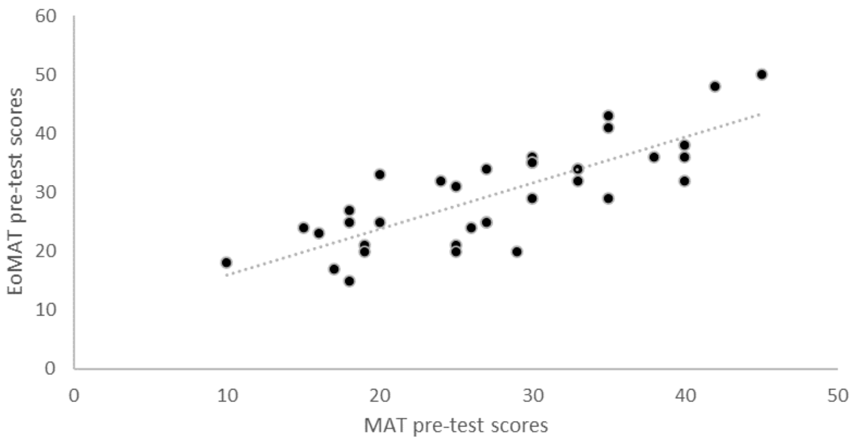


Figure 7: A scatter plot of EoMAT pre-test scores vs MAT pre-test scores.

Assumption #3: There should not be any significant outliers. Outliers are merely individual data points within a dataset that deviate from the norm. Figure 7, which was created using the EoMAT and MAT pre-test results, shows that the researcher did not find any notable outliers.

Assumption #4: The variables ought to roughly follow a normal distribution. Bivariate normality is required to evaluate the statistical significance of the Pearson correlation, but because this assumption is challenging to evaluate, a more straightforward approach is frequently used. This less complex approach is determining out whether each variable is normal separately. The simple Shapiro-Wilk test can be used to check for normality. The data I considered normal if the test's p-value is greater than 0.05. The Shapiro-Wilk test confirmed that data from the two variables did not show a significant departure from normality--MAT pre-test scores, $W(36) = .971$, $p = .451$ and EoMAT pre-test scores, $W(36) = .963$, $p = .267$, both p values > 0.05 .

Independent t-test

The second research question and hypothesis, which revolved around the significance in improvement between the two group post-intervention was investigated using the independent-samples t-test measure. The independent-samples t-test (or independent t-test, for short) compares the means between two unrelated independent groups on the same continuous, dependent variable. In this case, the dependent variable was the EoMAT post-test scores. The means of two independent groups are compared to determine whether there is statistical evidence that the associated population means are significantly different.

Since the independent t test is a parametric test that relies on assumptions about the population's distribution from which the sample was drawn, the data must satisfy these assumptions before the test can be run. Making sure that the data one needs to analyse can be analysed using an independent t-test is a step in the process when deciding to analyse data using an independent t-test. This is necessary because the data must "pass" six assumptions in order for an independent t-test to provide a valid result. Otherwise, the test should not be used. In practice, checking against these six assumptions merely adds a tiny bit more time to the analysis.

Prior to discussing the six assumptions, it is vital to note that one or more of these assumptions may be violated when analysing one's gathered data (i.e., is not met). Working with real-world data as opposed to academic examples makes this commonplace. Even though the data may contradict some assumptions, there is frequently a way to fix this.

Assumption #1: The dependent variable should be measured on a continuous scale (i.e., it is measured at the interval or ratio level) pre-test EoMAT scores for this study (measured from 0 to 100).

Assumption #2: The independent variable should consist of two categorical, independent groups. The dependent variable was divided into two groups, the experimental and the control groups.

Assumption #3: There should be no association between the observations in each group or between the groups themselves, which is referred to as observational independence. For this study, each group had a distinct individual, and no participant participated in more than one group. Although this is more of a problem with research design than anything that can be tested for, it is a key assumption of the independent t-test.

Assumption #4: There should be no notable outliers. Outliers are merely individual data points within a dataset that deviate from the norm. When the researcher looked at the post-test EoMAT results for both groups (ADDENDUM C), the researcher found no notable outliers.

Assumption #5: For each group of the independent variable, the dependent variable ought to have a distribution that is approximately normal. Since the independent t-test is relatively "resistant" to violations of normality, this assumption can be somewhat violated while still producing reliable findings. Testing for normality using the Shapiro-Wilk test of normality indicated that this assumption was not violated, W (36) = .957, p = .173, p value > 0.05.

Assumption #6: The variances must be homogenous. The variances are not statistically different from one another if the Levene test's p-value is greater than 0. 05. Using Levene's test for homogeneity of variances, this assumption was tested, and it was not violated p = 0.926 (p > 0.05).

3.6.2 Qualitative data analysis

According to Nowell et al. (2017), the processes of data collection, data analysis, and report writing are frequently interrelated and occur concurrently throughout the study process in qualitative research. Because data collection and analysis procedures may take place concurrently, it is important to note that the data analysis process may be indistinguishable from the actual data (Nowell et al., 2017). The approach for qualitative data analysis used in this study was developed from the works of Saldana (2013), Given (2008), Braun and Clarke (2013), Nowell et al., (2017), and Kruger and Casey (2015). This was an attempt to conduct an effective thematic analysis in order to achieve the requirements for trustworthiness.

As mentioned in the previous sections, the qualitative data for this study came in the form of focus group interviews via audio recordings and classroom observations notes. Although all types of data collected, such as audio recordings, transcriptions, documents, and field notes, are useful and required for completing a full study, the magnitude, complexity, and variety of formats of qualitative data frequently lack a uniform structure (Nowell et al., 2017). As a result, it is critical that researchers immerse themselves in the data to become acquainted with the depth and breadth of the content (Nowell et al., 2017).

Ideas and the identification of possible patterns may emerge as researchers become acquainted with all aspects of their data set. Before beginning coding, Nowell et al. (2017) recommend reading the entire data set at least once.

It becomes equally important for researchers to engage with the analysis as faithful witnesses to the data, being honest and vigilant about their own perspectives, pre-existing thoughts, and beliefs, and developing theories as needed (Saldana, 2013; Given, 2008; Braun and Clarke, 2013). Researchers can document their theoretical and reflective thoughts that develop through immersion in the data, including their values, interests, and growing insights about the research topic (Kruger and Casey,2015). As this step proceeds, researchers are usually encouraged to write notes regarding code ideas that can be revisited later. (Nowell et al., 2017). Prior to the analysis process, the researcher transcribed the interviews via intelligent transcription--transcribing every word, but making an interpretation to exclude pauses, status, and filler words and potentially cleaning up the grammar.

The researcher's experience:

As discussed in Chapter 3, the qualitative data for this study was constructed using focus group interviews that were audio recorded. All files (i.e., raw data) were labelled with the case from which the data was obtained, a unique identifier for the source (e.g., Experimental School), and the date created. These raw data files were kept in a centralised repository (a secure network location with folders for each type of raw data) and archived with dates to provide an audit trail and a way to check the data analysis and interpretations for accuracy. Excel was used to log all raw data and detail the progress in collecting and converting raw data to text that would later be analysed as the researcher transcribed the data from audio format to text. The NVivo software tool was used to help sort and organize the data collected, allowing the researcher to reorganize the data into a consistent framework and convert the Excel document into a Word document.

Following the familiarization of the qualitative data, the researcher then proceeded with the qualitative data analysis of the via thematic analysis. Each interview was read word for word, coding the results from the different interviews, identifying patterns, and grouping similar codes and themes of the learners' opinions on the style of teaching they had received into different categories. The goal was to find common patterns across the data set in order to produce a trustworthy and credible final narrative. Data from the classroom observations was cross referenced with data from the interviews to see if there were common themes between the two data sets. The researcher utilized a very basic structure process to identify themes from the focus group interviews.

The structure included 4 steps and they were:

(a) First round pass at coding data

Reading the transcribed interviews and assigning codes to various passages was essentially the first phase of coding qualitative data. This is usually a quick step. Researchers are not expected to be concerned about producing ideal codes at this level of coding because he would continue iterating and refining the codes as he progressed to the second pass and beyond (Saldana, 2013; Given, 2008; Braun and Clarke, 2013). The researcher uses the coding procedures that are widely employed in the first-round pass to determine how to name the codes and what elements of the data to code. Qualitative coding is a reflective strategy of interacting with and thinking about data. Coding allows the researcher to concentrate on specific data characteristics while also simplifying the data (Nowell et al., 2017). From unstructured data to establishing theories about what is happening in the data, researchers will progress. During coding, researchers choose relevant text chunks and label them so that they can be indexed according to a data theme or issue in the data (Nowell et al., 2017). Two coding techniques are usually used:

- **InVivo Coding - Using the participant's own words.**

In in Vivo coding, the researcher is supposed to code an excerpt based on the words of the participant, not on his own judgment as a researcher (Saldana, 2013; Given,2008; Braun and Clarke, 2013). The researcher tries to keep as near as possible to the participant's intent and meaning by using the participant's own spoken language. In Vivo coding is frequently utilized as a first step in distilling passages into single words or phrases taken from the interviews.

- **Descriptive Coding**

The researcher uses descriptive coding to try to condense the text's content into a description. The code name was a term or phrase that summed up the data's contents. A "code" that captures the phenomenon's qualitative richness is deemed a good code (Nowell et al., 2017).

The researcher's experience:

In conjunction with NVivo software, the following process, adapted from Kruger and Casey (2015), was used to organize the responses to the interviews.

(i) Did the participant answer the question?

YES - go to (iii)

NO - go to (ii)

(ii) Does the comment answer another question that was asked?

YES- move it to that question.

NO- Put it in a discard file.

(iii) Does the comment say something important about the topic?

YES- Place it under the appropriate questions.

NO- Put it in discard file.

(iv) Does the comment sound like something has been said earlier?

YES- Start grouping the comments together.

NO – Start a new separate grouping.

The NVivo software allowed the researcher to work efficiently with proper coding schemes and large amounts of text, allowing for greater depth and sophistication in the analysis process. The researcher's analysis of the data set increased the credibility of the analysis. The researcher worked methodically through the entire data collection, paying close attention to each data item. Various data extracts were descriptively coded in as many different themes as they fit and as frequently as they were deemed relevant. These “initial codes” were developed by summarising the participants’ responses to the questions to single words and phrases and these essentially formed the first themes where data qualitative data is concerned. This was essentially done deductively because the process was driven by the researcher's pre-existing theoretical or analytic interests. A memo was logged to identify interesting characteristics of the data and developing themes that may be underlying the data set.

Table 1: The initial codes developed to structure the data.

Theme, definition	Response
Connection---*Linking concepts and skills between the subjects, mathematics, and physical sciences to solve related problems.*	*Physics is hard, but this topic is way harder, the formulae…. I don't understand how to manipulate the formulae…..* *Choosing the correct formula to solve a particular physics problem….* *Struggled with substituting the correct values into the formular……* *Equations of motion is like maths, maths is hard.* *Maths and physics are hard enough on their own and together they are way worse....* *I feel like using the laws of exponents and algebra helped with understanding equations of motions….* *I did not know the graphs in maths are also there in physics.* *So, equations of motions is maths but with meaning* *I think using the maths helps with understanding with this section.* *This method helps, I wish the math teacher class could do the same as well, show us the relationship between the two…..maybe that could help us understand the maths better as well.* *Maybe if we were shown this in grade 9 our marks would be higher….* *Now I understand why they make us do pure maths when we choose physics, they're connected…….*

Mathematical Ability—*Ability of the learner to use formula when solving problems that require some calculations, fundamental mathematical concepts underpinning equations of motion*	*Choosing the correct formula to solve a particular physics problem….* *Struggled with substituting the correct values into the formular……* *Changing the subject of the formular….* *Equations of motion is like maths, maths is hard….* *I feel like using the laws of exponents and algebra helped with understanding equations of motions….* *I did not know the graphs in maths are also there in physics….* *So, equations of motions is maths but with meaning…* *I think using the maths helps with understanding in this section…* *This method helps, I wish the math teacher class could do the same as well, show us the relationship between the two…..maybe that could help us understand the maths better as well…..*
Physical Science concepts, Performance— *Learners' comprehension of the physical science concepts in mechanics, being able to solve problems*	*Struggled with the difference between acceleration and velocity……*

revolving around these concepts, grades of the learners	*Struggled with the difference between scalars and velocity….what is the difference between speed and velocity, displacement and distance…* *Understanding the difference between SI units for acceleration and velocity…* *I feel like using the laws of exponents and algebra helped with understanding equations of motions. …..* *I think using the maths helps with understanding with this section….* *Maybe if we were shown this in grade 9 our marks would be higher….*
Group work, Accentuating the pre-requisite mathematics-- *What the teacher does in class during lessons to reinforce learning*	*This method is a bit hard because now in the physics class, now the sir makes us focus both in physics and maths….* *Although we prefer to work alone and do the exercises myself…. sometimes, the teacher talks fast and doesn't allow us to ask questions when he's teaching so when we do exercises in classes we ask our smart friends for help….* *Sometimes the teacher uses big words when teaching so we end up not understanding what he's teaching. So we are forced to ask our friends for understanding and clarity…* *(Together) Oh yes, sometimes we need our smart friends to help us*
Lesson plans, Textbooks---- *Various paraphernalia to facilitate learning and teaching during lessons*	*Maybe the maths teacher and the physics teacher can design our lesson plans together…..* *Having a textbook that combines the two subjects would help……* *A textbook that shows maths and physics at the same time would help……*

(b) Organising the codes into categories and subcodes

The researcher begins grouping the codes into groups after the first round of coding. The researcher put together codes that are related to one another or pertain to the same themes or general notion within each category. A researcher is expected to go over these categories over and again, moving the codes about until he or she comes up with a framework that makes sense for the analysis (Saldana, 2013; Given, 2008; Braun and Clarke, 2013). To organize the codes and subcodes, the researcher used NVivo software.

The researcher's experience:

The qualitative data generated from the interviews were not so extensive that the researcher required a complex coding framework for developing broader, higher-order codes for organizing it. As mentioned previously, the initial codes were developed deductively and essentially formed the first themes and the researcher collected these initial themes as the parent themes. Details about the development of themes and subthemes were added to the codebook, which also included an audit trail to establish confirmability. Furthermore, to avoid losing miscellaneous codes, the researcher stored a copy in separate free nodes. Diagrams were also utilized to link and investigate themes deeper. Table 2 contains a more refined list of themes and subthemes for each topic. This process was not intended to create a model, but rather to visualise the themes and analyse the various ways in which they interact.

Table 2: Main themes and subthemes for the qualitative data

MAIN THEMES (CODES)	SUBTHEMES (SUBCODES)
Comprehension and Application	Physical Science and Performance, Mathematical Ability, Connection
Teaching Strategy	Group work, Accentuating the pre-requisite mathematics
Teaching and Learning Resources	Lesson plans, Textbooks

(c) Further rounds of coding qualitative data

This phase follows the initial coding and collation of all data, as well as the development of a list of the various codes identified across the data set. This stage entails organizing and categorizing any possibly relevant coded data extracts into themes (Nowell et al., 2017). The researcher may need to re-examine the codes and categories that have previously been generated during this phase. The researcher may have to rename, recode, merge codes, and re-categorize the data he has gathered thus far in this step. These rounds of coding are about re-analysing, identifying patterns, and getting closer to establishing ideas and notions, whereas the first round of coding is a bit haphazard. In general, the researcher should reduce the number of codes from the first round of coding and actively consider how to categorize the codes that remain (Saldana, 2013; Given,2008; Braun and Clarke, 2013). In the last stage of coding, thematic analysis is commonly used as a method of coding.

(i) Thematic Analysis Coding - Finding recurring patterns and themes

Thematic analysis coding is typically utilized when a researcher is looking for themes or patterns across his/her data set. If the researcher finds a pattern within different parts of the data or see that certain excerpts point to the same underlying idea or meaning, those excerpts are coded with a unifying code (Saldana, 2013; Given,2008; Braun and Clarke, 2013).

"A theme is an abstract entity that gives meaning and identity to recurring experiences and their various expressions. As so, a theme captures and unites the essence or foundation of the experience into a meaningful totality" (Nowell et al., 2017. p8). Themes can be identified by combining thoughts or experiences that are meaningless when evaluated separately. To determine a theme's relevance to the research question, all that is required is that it captures a substantial feature of that question.

Theme names, according to Braun and Clarke (2006), should be brief and express the theme's content immediately. There may be some overlap between topics for different data areas (Nowell et., 2017). At this point, researchers can consider how each theme fits into the overall picture of the entire data set in terms of research topics (Braun and Clarke, 2006).

Themes are supposed to be important notions that connect large chunks of data together. They can either be deduced from theory and earlier research or inductively derived from raw data (Nowell et al., 2017). Themes that are formed from the raw data itself follow an inductive approach, and they may have little relevance to the original questions posed to the participants. Rather than fitting data into pre-existing categories, data is coded using inductive analysis (Nowell et al., 2017). Data drives thematic analysis in this way.

Deductive analysis, on the other hand, is motivated by the researcher's theoretical or analytic interests, and while it may provide a more in-depth examination of some parts of the data, it leaves less room for summarizing the total data (Saldana, 2013; Given, 2008; Braun and Clarke, 2013). Researchers must distinguish between inductive and deductive thematic analysis because it affects the way themes are conceived (Saldana, 2013; Given, 2008; Braun and Clarke, 2013).

One advantage of thematic analysis is that it allows researchers to identify themes in a variety of methods; however, consistency is essential in any analysis. Tables, templates, code manuals, and mind maps can all be employed. Thematic networks can be constructed to organize codes and themes in a web-like manner, explaining the steps involved in translating text into meaning (Nowell et al., 2017).

For displaying relationships between themes, researchers might use generic data analysis tools or more creative and less structured approaches, such as maps, matrices, and other diagrams. It is important to note that for the reader to be able to judge whether the final outcomes are supported by the generated data, it is essential that the procedure for data collection, coding, organization, and analysis must be thoroughly described.

To help guide the analysis, a few predefined codes have been suggested as the best place to start when searching for themes. Nonetheless, researchers need to take note that too many predefined codes may prevent researchers from considering data that contradicts previous assumptions. Similarly, starting with too few predefined codes may leave researchers feeling lost and overwhelmed by the amount of complex data (Nowell et al., 2017).

Instead of attempting to analyse and interpret every code in the same depth, novice researchers should look for themes that are most relevant to gaining an understanding of the phenomenon being studied. Researchers should not be so swayed by research questions that themes that are not directly relevant are ignored initial codes may form main themes, while others may form subthemes. There may also be codes that seem out of place. A "miscellaneous" theme has been recommended for the temporary housing of codes that do not fit into the main themes (Nowell et al., 2017). A data or code cannot be abandoned during this stage because it is extremely difficult to determine whether a theme will hold or if the extracts will be combined, refined, separated, or discarded without a closer inspection of all the extracts (Nowell et al., 2017). Themes that seem irrelevant may add an important layer of background detail to the study. To establish confirmability, researchers should maintain a record of detailed notes concerning the emergence and hierarchies of concepts and themes (Nowell et al., 2017).

In this phase, it is recommended that the researcher review the coded data extracts for each theme at this stage to determine whether they appear to form a coherent pattern. Individual theme validity is evaluated to determine whether the themes accurately reflected the meanings evident in the data set as a whole. Importantly, as this phase progresses, deficiencies in the initial coding and themes are identified and may necessitate various changes (Nowell et al., 2017). If the researcher discovers a relevant issue in the text that is not addressed by an existing code, a new code may be added (Nowell et al.,2017).

Following this phase, it may become clear that some themes lack sufficient data to support them. Some themes may overlap, while others may need to be separated into separate themes (Braun and Clarke, 2006). It will be necessary to refine selected themes into themes that are specific enough to encompass a wide range of ideas within multiple text segments while remaining broad enough to encompass a wide range of ideas across multiple text segments. Themes should not be considered final until all data has been read and the coding has been double-checked (Nowell et el., 2017). Investing enough time in developing the themes will result in more credible findings (Nowell et al., 2017). A clear definition of what themes are and are not should be established (Braun and Clarke, 2006). Each theme should be derived from the data in a way that the researcher can explain. The data within themes must cohere meaningfully, with a clear distinction between each theme (Braun and Clarke, 2006). The researcher should have a firm grasp on the various themes, how they fit together, and the overall message conveyed by the data by the end of this phase (Braun and Clarke, 2006).

The researcher's experience:

During this phase, the researcher examined the coded data extracts for each subtheme to determine whether a consistent pattern existed emerged. The raw data was also examined to make sure the themes reflected the voices of the participants. As part of this process, the researcher attempted to write detailed analyses for each individual theme, identifying the story each theme told while considering how each theme fitted into the overall story of the entire data set in relation to the research questions.

The researcher ensured that the themes held true across the qualitative data collected by continually reading through and reviewing the data. As a result, some aspects of the research were exposed that would otherwise have remained unsaid. To ensure the credibility of the findings, the researcher reviewed all the data and scrutinized the coding before finalizing the themes. It was important to order the themes in a way that best reflected the data to tell the story. In the final step, the researcher reviewed all the themes to ensure that the words of participants were used in the names of themes, if not, then in the description of the names of themes.

(d) Turning codes and categories into a final narrative

At this point, the researcher had fully established the themes and was ready to begin the final analysis and write-up. After the rounds of coding qualitative data, the codes and categories were taken and used them to construct the final narrative. The aim of this phase of data collection was to generate a set of findings that can be used for deepening the quantitative data. In this phase the creativity of structuring a narrative was combined with the analytical nature of connecting the narrative to the codes and theories grounded in data (Saldana, 2013; Given, 2008; Braun and Clarke, 2013). The researcher began with the theory, findings, and narrative, and then referenced the codes and categories that were used to inform them. A thematic analysis should present the data in a concise, logical, non-repetitive, and interesting manner. Researchers are encouraged to explain clearly how they obtained their findings in a way that is accessible to a critical reader, so that the claims made about the data are credible and believable.

Researchers should keep methodological notes, trustworthiness notes, and audit trail notes to help with the reporting process. It is critical to include direct quotes from participants in the final report. Short quotations may be included in the text to demonstrate the ubiquity of the themes and to highlight specific points of interpretation (Nowell et al., 2017).

More extensive quotations may be included to give readers a sense of the original texts. If researchers simply report the codes and themes that appear in the transcripts, the results will be descriptive rather than deep, failing to do justice to the data's richness (Nowell et al ., 2017). Extracts of raw data must be embedded in the analytic narrative to effectively convey the true story of the data, going beyond mere explanations of the data. The reader will be convinced that the analysis was valid and worthwhile in this manner (Nowell et al ., 2017).

Researchers should move from description, in which data are simply organized and summarized to show patterns, to interpretation, in which researchers attempt to theorize the significance of the patterns and their broader significance, in relation to literature. Researchers can evaluate whether their findings and conclusions have been interpreted credibly and whether the literature supports their conclusions by reviewing their reflexive journals (Nowell et al ., 2017).

Researchers can develop a valid argument for selecting the themes by reviewing the literature. Literature and findings can be interwoven to build a compelling story (Nowell et al., 2017). A researcher may also propose new theoretical or practical interpretations of the subject in addition to providing plausible interpretations as well as verifying the research findings, the literature can also be used to challenge and add to the research (Nowell et al., 2017). To be considered analytically credible, the argument must be coherent. The trustworthiness of the process is dependent on how the researcher uses the data to support their main points, building toward a convincing conclusion (Nowell et al., 2017). To make the discussion credible, the researcher should discuss all relevant outcomes, including results that were unexpected or did not correspond to the main explanations for the phenomenon being studied (Nowell et al ., 2017). Some authors believe that researchers should present the meaning of each theme, as well as the assumptions that support it and the implications of each theme. Authors frequently advise submitting the final analyses to participants for feedback via the member checking process in order to create an overall story about what the various themes reveal about the topic (Nowell et al., 2017). Lastly, member checking provides the researcher with the opportunity to see how the researcher's representation of the respondents matches the respondents' views (Nowell et al., 2017).

The researcher's experience:

Following the completion of the themes, a report was written (section 4.5). The report included both short and long quotes, and each quote was accompanied by a unique identifier to show that different participants were represented. Themes, subthemes, and exemplar quotes are presented in Tables 1 and 2. In the final discussion section, all themes, including discrepant data, were discussed. During the discussion, the researcher referred back to the original literature that influenced the study, as well as research and other literature that supported his argument. He compared his findings to the larger literature, noting where they were supported, contradicted, or added to the existing body of knowledge on the subject.

3.6.3 Trustworthiness of the Qualitative Data

When collecting and analysing qualitative data for the study, it was important to consider validity and reliability. Practicing reflectivity is one of the most important approaches practiced increasing the qualitative data's trustworthiness (Saldana, 2013; Given, 2008; Braun and Clarke, 2013).

Practicing Reflexivity

While collecting the data, I kept this practice of reflexivity that involves examining your own judgments, practices, and beliefs in the back of my mind at all times. By doing so, (In reflexivity), I (the researcher) identified any personal beliefs that may have had an impact on my research (Saldana, 2013; Given, 2008; Braun and Clarke, 2013).

3.6.4 Triangulating, Complementing and Deepening of collected data.

When the quantitative and qualitative data collection and analysis were done, the researcher wanted to see if the two data sets would at some point converge via triangulation, complementing and deepening data analysis processes. The triangulation of data involves demonstrating how quantitative and qualitative data collected in the study are validated between each other. Triangulation means that the quantitative and qualitative data match, point in the same direction or converge on some aspects of the research problem (Ponce and Maldonado, 2014). Triangulation of data increases the validity of the study and facilitate inferences and conclusions that can be stated about the findings (Doyle et al., 2009).

Complementing in data analysis means using quantitative and qualitative data to complement when presenting the findings. Complementary means that data supports each other. In this case, the quantitative data sets the scope of the measure, and the qualitative data deepens it or one data set complements the other (Ponce and Maldonado, 2014).

Deepening in data analyses means using quantitative and qualitative data to bring the argument to a point of no refutation. In this analysis, the amount of quantitative and qualitative data provides an overview of the research problem. While in "triangulation", quantitative and qualitative data point in the same direction, in "complementing" a set of data supports the other; in "deepening" the quantitative and qualitative data provide a comprehensive and clear view of the research problem (Ponce and Maldonado, 2014). The quantitative and qualitative data are used to bring the argument to a point where there is no doubt regarding the findings of the study or to a point of no rebuttal because a comprehensive picture of the topic is provided (Doyle et al., 2009).

Triangulation, complementing and deepening analysis processes were used to see if the data the pre-test and post-test quantitative data and the qualitative data from the interviews converges at some point, with the aim of establishing how the results from the various data collection sets/sources compare and if they consistent or not, and to prove the hypotheses. Through triangulation, complementing and deepening of the quantitative and qualitative data sets, the researcher sought to conduct a study that has validity and reliability.

3.7 Validity and Reliability for the Mixed Method Approach

Ponce and Maldonado (2014) and Doyle et al., (2009) mention that when utilizing a mixed methods approach for a study, its validity is ensured by means of data analysis processes such as triangulation, complementing and deepening. Triangulating, complementing, and deepening the data analysis by using mixed methods enabled the researcher to construct deeper and more meaningful interpretations of the phenomenon, in terms of the teaching methods and the setting for the investigation, which is a real-world setting. The researcher was able to be confident in his findings for this study, as discussed in section 1.8. Doyle et al., (2009) and Ponce and Maldonado (2014) mention that such techniques often reveal areas of contradiction and inconsistency, and this often leads to creative explanations or adjustments to better create convergence, if possible. Ponce and Maldonado (2014) and Doyle et al. (2009) conclude that these techniques allow researchers to use of more than one line of sight and thus which enable them to offer a richer, complex interpretation of the reality in which the study is grounded.

3.8 Ethics

To conduct this study the researcher applied for and was granted permission by the Cape Peninsula University of Technology (CPUT), the Research Ethics Committee (REC) (Human Research) for ethical clearance at the University, as well as the Western Cape Education Department (WCED) (Addendum G).

The results of achievement tests and audio recorded interviews were used to collect data. The primary data sources were grade 10 learners. According to Maree (2021), before any data collection takes place, a researcher should consider the welfare of participants, the protection of participants, the feeling that participants have contributed to social research, and finally the choice of participation. All potential participants were approached fairly and informatively, and participation was entirely voluntary. Given that the learners are younger than 18 years, permission was sought from their parents and legal guardians. Furthermore, the learners were given informed consent forms to complete that allowed the researcher to use the collected data in the study (Addendum H). Participants were informed of the study's potential contribution to educational research in a South African context, emphasizing the service they would be providing to their community by participating. The participants remained anonymous throughout the study, and participation posed little to no risk to them. The schools where the teaching sessions took place were also required to give permission for data collection. Both participants and schools were informed that they could opt out at any time during the study, and this was done before any data was collected. After the data was collected in an ethical and considerate manner, the data analysis began, as discussed in the following chapter.

3.8 Summary

This chapter discussed and supported the specifics of the mixed methods study's research design and methodology. The procedures and tools for data collection and analysis were described, the quantitative and qualitative aspects of the study detailed, as well as the point of integration in the mixed methods study. The participating groups and setting were described, as well as the ethical considerations for the participants. Finally, the study's reliability and validity were discussed. The researcher then presents the study's findings and data analyses in the following chapter.

CHAPTER 4

RESULTS AND DATA ANALYSIS

4.1 Introduction

The primary research questions the study aimed to investigate is:

What is the relation between grade 10 learners' mathematical competency and their understanding of equations of motion in physical sciences? The following sub-questions guided the study and the analyses of data sets:

Sub-questions

- Is there a statistically significant relationship between grade 10 learners' mathematical competencies and their understanding of equations of motion in physical science?
- Is there a statistically significant improvement in the performance of learners in equations of motion when exposed to a mathematical enriched instructional strategy compared to those learners exposed to the conventional approach to the teaching of equations of motion?

This chapter presents and organizes the quantitative and qualitative findings from the pre-test and post-test, as well as the focus group interviews and data analyses. This data is discussed in detail in Chapter 5. A mixed methods approach allows the researcher to consider not only the "what," but also the "how" and "why" of the research problem and findings (Maree, 2021). This allows for a more comprehensive interpretation and understanding of the research problem and research findings.

The chapter begins with a succinct presentation of the quantitative data obtained from the experimental and control groups then followed by that of the experimental group interviews, where noteworthy observations were highlighted. The research sub-questions and hypotheses are addressed in terms of the quantitative results obtained.

4.2 Biographical Information

Convenience or an intact sample of learners whose ages ranged from 14 years to 16 years was used for data collection. From both schools, experimental and control, in the year preceding the study, the learners performed poorly on grade 12 physical science examinations. The physical science performance of the participating schools, experimental and control, was 45 % and 47%, respectively.

4.3 Results of quantitative data collection tools

The quantitative effects of the researcher's collaborative approach (group approach) teaching strategy that accentuates the mathematics required for conceptual understanding of equations of motion and the conventional teaching strategy are determined by using quantitative results obtained and analysis. Furthermore, the quantitative analysis results were used to answer the study's research questions. The learners took part in all experimental activities, including attending all lessons during the two-week intervention, participating in classroom activities in both groups, and completing the pre-tests (EoMAT and MAT) and post-test (EoMAT). In order to see how reliable, the EoMAT and MAT test items were, the researcher used the Kuder-Richard-20 formular to determine the reliability coefficients. For the EoMAT, he obtained a reliability coefficient of 0.82 and for the MAT he obtained a reliability coefficient of 0.90. Such high values suggested internal consistency of the tests as test items within the 0.80 to 0.85 range are preferred. The difficulty indices for the EoMAT and MAT were 0.64 and 0.67 respectively. Lastly, the discrimination indices were looked at as well. Both the EoMAT and MAT had discrimination indices of 0.34 and 0.36 respectively. Items which discriminate well are those which have difficulties between 0.3 and 0.7. The purpose of the tests was to discriminate between different levels of achievement, so items with difficulty values between 0.3 and 0.7 were considered most effective.

The experimental school's MAT pre-test mean score was 34.72, while the control schools' mean score was 20.5. The experimental school's mean EoMAT pre-test score was 35.17, while the control school's mean was 24.17 (ADDENDUM C). The descriptive statistics for the results obtained for each of the groups can be found in tables 3 and 4 below.

Table 3: Descriptive statistics for the experimental group

Experimental Group (N=18)	Pretest (MAT)	Pretest (EoMAT)	Post-test (EoMAT)
Mean	34,72	35,17	36,89
Std. Deviation	5,11	7,37	8,47

Table 4: Descriptive statistics for the control group

Control Group (N=18)	Pretest (MAT)	Pretest (EoMAT)	Post-test (EoMAT)
Mean	20,5	24,17	23,61
Std. Deviation	4,76	5,54	5,85

The difference in MAT pre-test means was 14.2 marks, while the difference in EoMAT pre-test scores was 11. Although the differences are slightly greater than ten marks, the researcher believes that there is a sort of baseline equivalence between the two groups prior to intervention, because both were underperforming, based on the grade 12 results of their schools prior to the study. The EoMAT post-test results indicated that the treatment was effective in the experimental schools where it was implemented. The experimental schools' mean post-test score was 36.89 (SD = 8.47; N1 = 18), while the control schools' mean score was 26.61 (SD = 5.85; N2 = 18).

According to the Pearson product moment correlation the EoMAT and MAT pre-tests were strongly correlated, $r(34) = .7999$, $p < .00001$. This indicated a positive correlation between the two variables as the obtained r value was between +0.5 and +1 (ADDENDUM E).

An independent t-test was run on the EoMAT post-test scores, and the following were obtained (ADDENDUM F). The 18 participants who received the intervention in the experimental group (M = 36.89, SD = 8.47) compared to the 18 participants in the control group (M = 23.61, SD = 5.85) demonstrated significantly better improvement in the EoMAT post-test scores, $t(34) = 5.47$, $p < .00001$.

4.4 Discussing the research sub-questions and hypothesis in terms of quantitative results.

Research sub-question 1

- Is there a statistically significant relationship between grade 10 learners' mathematical competencies and their understanding of equations of motion in physical science?

The Pearson-correlation yielded, $r(34) = .7999$, $p < .00001$, from the EoMAT and MAT pre-test scores, suggesting a positive correlation between the two and a statistically significant relationship between the learner's mathematical competencies and their understanding of equations of motion.

Research sub-question 2

- Is there a statistically significant improvement in the performance of learners in equations of motion when exposed to a mathematical enriched instructional strategy compared to those learners exposed to the conventional approach to the teaching of equations of motion?

The independent t-test results indicate that there is a statistically significant difference in achievement post treatment between the groups as indicated $t(34) = 5.47$, $p < .00001$. This means that the experimental schools' collaborative (group approach) teaching strategy, which emphasized the mathematics required for conceptual understanding of equations of motion, outperformed the control school's conventional teaching approach in improving learners' performance in certain topics in grade 10 equations of motion.

Research Hypothesis 1

- H_o. There is no statistically significant relationship between achievement in equations of motion and level of mathematical competencies and knowledge by grade 10 physical science learners in this study.

Research Hypothesis 2

- H_{o1}. There is no statistically significant improvement in achievement in equations of motion between grade 10 physical Science learners taught with a mathematical enriched instructional strategy compared to those learners exposed to the conventional approach to teaching.

Both null hypotheses are rejected. As mentioned, due to the Pearson correlation coefficient results obtained, there is a statistically significant relationship between the learner's mathematical competencies and their understanding of equations of motion. Results from the independent t-test indicate that there is a statistically significant difference in achievement post treatment between the groups as indicated by the results obtained. As mentioned, this means that the experimental schools' collaborative (group approach) teaching strategy, which emphasized the mathematics required for conceptual understanding of equations of motion, outperformed the control school's conventional teaching approach in improving learners' performance in certain topics in grade 10 equations of motion.

4.5 Results of the qualitative data interviews

After conducting the focus group interview with 8 learners from the experimental group the following section below provide a succinct summary of the main findings related to the questions asked.

Question 1: What are the main challenges you encounter during physics lessons on equations of motion? (Refer to the physics concepts, the mathematics required to solve such problems and the language used in such a lesson).

Most of the learners had the following to say:

A. *Physics is hard, but this topic is way harder, the formulae…. I don't understand how to manipulate the formulae…..*
B. *Choosing the correct formulae to solve a particular problem….*
C. *Struggled with substituting the correct values into the formular……*
D. *Changing the subject of the formular….*
E. *Struggled with the difference between acceleration and velocity.*

F. *Struggled with the difference between scalars and velocity….what is the difference between speed and velocity, displacement and distance*
G. *Equations of motion is like maths, maths is hard.*
H. *The correct SI units for acceleration and velocity……*

Majority of the responses agree with the researcher gathered from the literature review, section 2.5-- that the use of mathematics where physics, particularly, mechanics is concerned remains a complex problem for learners and students. When solving equation of motion problems, choosing the correct formulae for different scenarios, formulae manipulation, correct substitution of values into the formulae, are all skills rooted in mathematics that learners and students require as prerequisite knowledge if their performance is to improve in the mechanics' class.

Two learners mention that they "struggled with the difference between acceleration" and "*struggled with the difference between scalars and velocity….what is the difference between speed and velocity, displacement and distance?"* . This suggests that learners are struggling with conceptual understanding. And if a learner struggles with understanding the very concepts themselves, how can they hope to solve problems where those concepts are applied.

Question 2: How did you find the lessons presented to show the connection between science and mathematics? Do you think the connection between the two should always be made apparent in a lesson before introducing you to a topic like this?

Most of the learners had the following to say:

A. *Maths and physics are hard enough on their own and together they are way worse.*
B. *I feel like using the laws of exponents and algebra helped with understanding equations of motions….*
C. *I did not know that the graphs in maths are also there in physics, but now I know……*
D. *So equations of motions is maths but with meaning…….*
E. *I think using the maths helps with understanding with this section….*
F. *I think teaching and learning physics this way helps……*

Majority agreed they found the lessons very informative and helpful. Making sure that learners see the connections between mathematics and science is the researcher explored in section 2.5 of the literature review.

Question 3: Do you think being taught equations of motions using a strategy that address the mathematical knowledge needed to enhance understanding of science is the best way to learn physical science?

Most of the learners had the following to say:

A. *This method is a bit hard because now in the physics class, we have to focus both in physics and maths….*
B. *Now I understand why they make us do physics and maths….*
C. *Having a textbook that combines the two subjects would help….*
D. *This method helps, I wish the math teacher class could do the same as well, show us the relationship between the two….maybe that could help us understand the maths better as well.*

One of the learners found the method challenging as their response "*This method is a bit hard because now in the physics class, we have to focus both in physics and maths".* One learner mentions says "*Now I understand why they make us do physics and maths",* proving advocating for the premise of the study that mathematics is an integral part of science education. One learner mentions said that "*Having a textbook that combines the two subjects would help",* indicating the very serious need for the relationship between mathematics and science to be made apparent in the classroom.

Question 4: How important is information from other group members to you?

Most of the learners had the following to say:

A. *Although we prefer to work alone and do the exercises myself…. sometimes, the teacher talks fast and doesn't allow us to ask questions when he's teaching so when we do exercises in classes we ask our smart friends for help….*
B. *Sometimes the teacher uses big words when teaching so we end up not understanding what he's teaching….*

According to one response, learners preferred a learner-centered approach (group approach) in which they could share and discuss their mathematics and physics ideas. One of the responses hints at the issue of language---language being in an issue in science education.

Question 5: Do you think it is a good idea to group together high-performing and low performing learners in science and mathematics? Why?

Oh yes, sometimes we need our smart friends to help us… (all agreed on this)

This response provides evidence that learning primarily occurs through mainly through interactions with peers, teachers, and parents, while on the other hand, teachers stimulate and facilitate conversation through harnessing the natural flow of conversation in the classroom as mentioned through section 3.6.1 of the literature review.

Question 6: Do you think such an instructional approach can improve your performance in science? If not, in what way would you benefit from lessons the most when you're being taught Science?

Most of the learners had the following to say:

A. *A textbook that shows maths and physics at the same time would help…..*
B. *Maybe if we were shown this in grade 9 our marks would be higher…*
C. *Maybe the maths teacher and the physics teacher can design our lesson plans…..*

Responses indicate that the learners approve of this method and that having resources such as lessons plans and textbooks where mathematics and sciences are integrated has the potential to improve their performance in physical sciences.

4.5 Summary

In this chapter, the quantitative results, that is, the pre-test and post-test scores from EoMAT and MAT and Pearson-correlation and independent samples t- test analyses by means of descriptive statistics and SPSS program output were presented (section 4.3). Thereafter each research sub-question was addressed through the relevant statistical analysis obtained. Qualitative data in the form of interview questions and responses were summarised and noteworthy observations were pointed out by means of direct quotations. These quotations also reveal why and how certain codes were assigned, In the following chapter I will discuss the quantitative and qualitative results obtained, to see if there is some convergence between the two and what that means where related literature is concerned. The analyses of data in this chapter informed the discussion in the next chapter.

Chapter 5

DISCUSSION OF RESULTS, CONCLUSIONS, and IMPLICATIONS OF THE STUDY

5.1 Introduction

The data collection methods in this study took the form of achievement tests and focus group interviews. The achievement tests were the EoMAT and MAT, as previously explained, and focus group interviews, which were coded using pre-determined categories, as previously explained. This data was then analysed quantitatively and qualitatively to investigate emerging concepts to potentially address the pre-determined research sub-questions and, finally, to discuss the study's main research question: "What is the relation between grade 10 learners' mathematical competency and their understanding of equations of motion in physical sciences?". The quantitative data analysis was conducted via Pearson-product moment and independent t-test and qualitative data analysis was conducted via thematic analysis, as explained in the previous chapter. Data from both analyses was combined (implicitly) to strengthen the observations and findings of this study.

This chapter begins by discussing the research sub-questions and hypotheses with regards to the quantitative and qualitative results obtained and then from there, the main research question is discussed. This is followed by findings from the literature reviewed to support or explain some of the combined findings. Where possible, the findings will be aligned with previous studies' findings. The chapter will then conclude with general observations and findings from the entire study.

5.2 Addressing the research questions.

The sub-questions, as set out in Chapter 1, were examined in order to address the main research question which was "What is the relation between grade 10 learners' mathematical competency and their understanding of equations of motion in physical sciences?"

5.2.1 First research sub-question

- Is there a statistically significant relationship between grade 10 learners' mathematical competencies and their understanding of equations of motion in physical science?

This sub-question focused on the relationship between grade 10 learners' mathematical competencies and their understanding of equations of motion in physical science. Quantitative data obtained showed a statistically significant relationship between the two. The qualitative data obtained showed similar trends, that the relationship between the two disciplines is very clear. Both the quantitative and qualitative data in relation to this sub-question were very consistent to the literature reviewed for this study—that the connection between the two disciplines cannot be denied (see section 2.5).

5.2.2 Second research sub-question

- Is there a statistically significant improvement in the performance of learners in equations of motion when exposed to a mathematical enriched instructional strategy compared to those learners exposed to the conventional approach to the teaching of equations of motion?

This question focused on whether there would be an improvement in the performance of learners in equations of motion when exposed to a mathematical enriched instructional strategy compared to those learners exposed to the conventional approach to the teaching of equations of motion. Quantitative data obtained showed a statistically significant difference between the two and as mentioned, this meant that the intervention strategy employed, that is the collaborative approach (group approach) teaching strategy that accentuates the mathematics required for conceptual understanding of equations of motion, as implemented in the experimental schools, was effective compared to the conventional teaching approach implemented in the control school in substantially improving learners' performance in certain topics in grade 10 equations of motion. Qualitative data obtained was consistent with the quantitative data obtained and the literature review of the study---that a proper background in mathematics is key for success in science education, especially in physics.

5.3 Main research question discussion and integrated discussion of results

The main research question was "What is the relation between grade 10 learners' mathematical competency and their understanding of equations of motion in physical sciences?" The quantitative results obtained confirmed the close association between the two disciplines. This study also sought to compare the effectiveness of a learner centred collaborative approach (group approach) teaching strategy, conforming to the standards of social constructivism, that accentuates the mathematics required for conceptual understanding of equations of motion. Quantitative results obtained also confirmed that the learners in the experimental school, who were exposed to lessons that took the form of the intervention teaching strategy, performed significantly better compared to the learners who were exposed to a conventional teaching strategy in the control school.

These findings were also consistent with qualitative findings from the semi-structured interviews which suggested that this strategy may have the potential to influence the academic achievement of learners in physical science. The learners' responses from the focus-interview questions show the importance of emphasising mathematics and its place in the physics classroom. All responses related the importance of mathematics in physics shows how the interconnections made between mathematics and physics (on the topic equations of motions) can help learners see beyond the abstract concepts, theories and laws behind physics. This is substantiated by a collective agreement by all when they said “Now I understand why they make us do physics and maths…” This indirectly implies that by incorporating mathematics it strengthens their understanding of application and analysis in physics which have the potential to expand the cognitive domain of the taxonomy of educational objectives in physics.

The qualitative findings of this study imply that if effort is not made to give physics learners and students a sound background in mathematics, their understanding of physics concepts may be limited, and this may hinder their ability to pursue their dream career in Science and Technology. Also, the use of instructional methods that are learner-centred, interactive and practical-oriented may enhance the performance of learners in physics concepts. Based on the findings of this study, it is recommended that: 1. Sound mathematics background should be ensured for physics learners and students alike in order to enhance their performance in physics concepts. 2. Interactive (collaborative) should be used in teaching physics concepts. Ogekunle and Obafemi (2013) also concur that interactive methods should be used in the teaching of physics concepts.

Though it is a known fact that mathematics and science are interconnected, teachers are unable to reflect this relationship in the current curriculum (Kiray, 2012). A primary reason for this disability is a discipline-oriented curriculum. Teachers find themselves limited to the science course or the mathematics course due to the current curricula. As a result, they feel that they are unable to teach the other course (Kiray, 2012). Taking this into account, the balance model offers teachers a wide range of integration options. Responses from the focus group interviews go as so far as say “A textbook that shows maths and physics at the same time would help, maybe if we were shown this in grade 9 our marks would be higher, maybe the maths teacher and the physics teacher can design our lesson plans”. This indicates that maybe the integration process of the two subjects is a multifaceted endeavour that begins with simple steps and tasks. Kiray (2012) concurs that such strategies, which can be viewed a simpler version of an integrated curriculum, may improve the self-efficacy of teachers over time, allowing them to achieve total integration of the two disciplines.

On the other hand, when it comes to the use of interactive (collaborative) learning and teaching strategies for effective teaching in science, certain studies outside science education have come to support the notion that these types of strategies are also effective in teaching content outside science when used properly. Dlamini and Mogari (2013), for example, investigated the impact of a group approach on low-performing mathematics learners' mathematics performance. Teachers in experimental schools used a group learning approach to teach mathematics, whereas teachers in control schools used traditional non-group teaching approaches. According to the quantitative findings, a group approach was more effective than traditional teacher instruction. The study also concluded that a group approach has the potential to influence the academic achievement of mathematics learners.

Based on a review of 80 studies in mathematics, Davidson (1985) compared group instruction with conventional whole-class instruction. In more than 40% of the studies reviewed, learners in group learning approaches outperformed control learners on individual mathematical performance measures. Kirschner et al. (2009) discovered that individual learning is less effective and efficient than group learning during mathematics tasks. Since mathematics courses allow for the adoption of social constructivist approaches to teaching so too can the science courses (Kiray, 2012). So it is safe to assume that certain social constructivist strategies used for teaching in mathematics can be adapted for teaching science as well. Learner centred approaches such as the group approach investigated by Dlamini and Mogari (2013) is an example of such strategies.

Allowing learners to sit in groups for learning purposes provided an opportunity for group discussions which included verbalising explanations, justifications and reflections giving mutual support and developed arguments about difficult problems. Dlamini and Mogari (2013) mentions the same as well. Dlamini (2012), for example, emphasizes three aspects of group learning activities: discussion, argumentation, and reflection.

According to Dlamini and Mogari (2013), learning in this type of environment also enables learners to deal effectively with individual working memory limitations. This is significant because group approach environment members have greater processing capacity, which promotes the development of task-related schemas (Dlamini and Mogari, 2013).

There is empirical evidence that quality improvement in the education of science and mathematics can be achieved through a variety of methods. However, this study revealed the importance of integrating programmes. A few experiments have been conducted on the integration approach. Most of these studies asked teachers to develop and implement an integrated science and mathematics curriculum. Other ways of implementing an integrated curriculum include giving teachers or student teachers the general heading "science and mathematics integration" and asking them to then design and implement an integrated curriculum based on their own understanding. Due to their lack of theoretical knowledge about the subject, however, teachers and student teachers are unable to develop and implement an integrated curriculum (Kiray, 2012). Also, deficiencies in mathematics and science content knowledge may be an impediment as well.

According to Koopman (2017), a developing concern about the low degree of SMK and PCK that science educators possess has been recognized. These concerns accept that a mutilated comprehension of the science subject matter teachers can hinder effective instruction of science instruction. For example, a study conducted by Basson and Kriek (2012) where the level of subject matter science teachers possess in South Africa was researched revealed that science educators in schools from the townships found the substance above their teaching capability. “Teachers’ poor grasp of the knowledge structure of mathematics and science acts as a major inhibition to teaching and learning these subjects” (Kriek and Grayson, 2009:186). The researchers concluded that several teachers in those areas were not qualified or not confident enough to properly physical sciences. Due to the poor content knowledge of science teachers and the fact that some teachers are trapped in traditional conventional pedagogies has resulted learners to perceive the subject as difficult (Koopman, 2017; Koopman, 2018).

A centralized education system, such as the one in South Africa, is also problematic at times because decision-making when it comes to education is centralized at the top, consolidating authority and power. Almost all decision making and authority rests solely with the top tier of management, which may only consist of a few individuals who dictate policy and make all the crucial decisions. Hence, centralization minimizes the role or involvement of teachers at the bottom levels.

The balance model was developed to provide teachers and student teachers with a detailed explanation of the overall process. The advantage of the model is that it allows the curriculum to be developed over a long period of time. As a result, teachers may take longer to plan a curriculum (Kiray, 2012). Because the balance model does not disregard content-specific knowledge, a significant disadvantage for the implementation of the curriculum in countries (such as South Africa) where centralised examinations are common is eliminated (Kiray, 2012). Therefore, parents’ anxiety will also be eliminated as the content is studied in full. Thus, teachers can easily use the model since it meets the expectations of both parents and educational institutions. It may be suggested that teacher training institutions use the balance model to develop student teachers' integration of science and mathematics, as well as the related content, skills, affective characteristics, teaching methods, and assessment methods. Using this model, teachers can be trained to teach an integrated scientific and mathematical curriculum.

Finally, the researcher acknowledges that science education has frequently been viewed as a solitary, individualistic, or competitive activity in which one sits, ignores the mathematics involved, and solves problems alone. As a result, it was asked at the outset of this study: What is the relationship between grade 10 learners' mathematical competency and their understanding of equations of motion in physical sciences? The findings of this study, as well as those of other related studies, suggest that an interactive learning approach (group learning) and an emphasis on the mathematics underpinning science may have a place in science education. The qualitative findings of this study, in particular, provide some evidence to suggest that a collaborative (group approach) that emphasizes the mathematics underpinning the science is beneficial. This study's qualitative findings, in particular, provide some evidence that a collaborative (group approach) that emphasizes the mathematics underpinning the science may be an effective way to teach certain topics in grade 10 physical sciences.

5.4 Implications and further research

From the quantitative and qualitative data of this study, it was seen that there was a relationship between the mathematical competencies and understanding of equations of motion at Grade 10 level and that a tailored an interactive (group approach), teaching strategy that integrates the required mathematics and physics can improve achievement in physical sciences.

However, the researcher believes that for further research, a study within a South African context, it would be more beneficial to investigate how specific topics and skills in mathematics influence the understanding of certain related physical sciences topics in grade 10.

Perhaps such a study would start off as an exploratory study (i.e., qualitative data collection to see which topics may influence the comprehension of certain physical science topics) followed by a quantitative experimental design to see if those topics actually influence the understanding of specific physical science topics. From the literature review of this study, a lot of emphasis was placed at tertiary level with regards to studies such as these, however the researcher strongly believes science education would benefit more if such a study was contextualized at grade 10 level.

Developing a learner and teaching tool, such as a textbook, that emphasizes the much-embedded mathematics in physical sciences may be used to study its influence science on the comprehension of physical sciences topics within the South African science classroom may be beneficial as well. Lastly, those who train teachers might want to look into the extent to which the CAPS curriculum for science allows for highlighting embedded mathematics, as many science teachers rely on this document to inform their PCK. This could result in revised curriculum approaches and, as a result, modified teacher training programs.

5.5 Final chapter summary

The researcher addressed each of the research sub-questions briefly in this chapter and used these to reach a conclusion on the relationship between grade 10 learners' mathematical competency and their understanding of equations of motion in physical sciences. The researcher also made recommendations for future research and considered the findings' implications for science teacher training efforts.

REFERENCES

Adegoke, B. A., 2009. Determining factors in secondary school students' choice of physics. *Journal of Science Teachers' Association of Nigeria,* 4(1 & 2), pp. 75-84.

Adeyemo, S. A., 2010. The Impact of Information and Communication Technology (ICT) On Teaching and Learning of Physics. *International Journal of Educational Research and Technology,* 1(2), pp. 48-59.

Aguirre, J. M., 1988. Studen Preconceptions about Vector Kinematics. *The Physics Teacher,* 26(4), pp. 212-216.

Akatugba, A. H. & Wallace, J., 2009. An interactive perspective on students' proportional reasoning in high school physics in a West African context. *International Journal of Science Education,* 31(11), pp. 1473-1493.

Apata, O. A., 2019. Predictive Validity of School and Student Factors on Secondary School Students' Academic Perfomance in Physics. *Journal of Research snd Method in Education,* 9(5), pp. 34-42.

Araujo, I. S., Veit, E. A. & Moreira, M. A., 2008. Physics students' performance using computational modelling activities to improve kinematics graphs interpretation.. *Computers and Education,* 50(4), pp. 1128-1140.

Asgari, S. & Nunes, M. B., 2011. *Experimental and Quasi-Experimental Research In Information Systems,* Sheffield: University of Sheffield.

Azzarito, L. & Ennis, C. D., 2003. A sense of connection: Toward social constructivist physical education. *Sport Education,* 8(2), pp. 179-197.

Bar, R. B. & Tagg, J., 1995. From teaching to learning--a new paradigm for undergraduate. *Change: The Magazine of Higher Learning,* 27(6), pp. 12-25.

Baskav, Z., Alev, N. & Karal, I. S., 2010. Physics and mathematics teachers' ideas about topics that could be related or integrated. *Procedia Social and Behavioral Sciences,* 2(2), pp. 1558-1562.

Bason, I. & Kriek, J., 2008. *Implementation of the new FET Physical Sciences curriculum: teachers' perspectives.* Maseru, Proceedings of the 15th Annual Conference of the Southern African Association for Research in Mathematics, Science and Technology Education.

Basson, I. & Kriek, J., 2012. Are grades 10–12 Physical Science teachers equipped to teach Physics? Perspectives in Education. 30(3), pp. 110-122.

Bay, E., Bagceci , B. & Cetin, B., 2012. The Effects of Social Constructivist Approach on the Learners' Problem Solving and Metacognitive Levels. *Journal of Social Sciences,* 8(3), pp. 343-349.

Berlin , D. & White , A., 1992. Report from the NSF/SSMA Wingspread Conference: A network integretad science and mathematics teaching and learning. *School Science and Mathematics,* 92(6), pp. 340-342.

Bernhard, J., 2000. *DOES ACTIVE ENGAGEMENT CURRICULA GIVE LONG-LIVED CONCEPTUAL UNDERSTANDING?.* [Online]
[Accessed 6 November 2019].

Braun, V. & Clarke, V., 2006. Using thematic analysis in psychology.. *Qualitative Research in Psychology,* Volume 3, pp. 77-101.

Chapple, M., 1974. *"A" level Physics Volume 1- Mechanics and Heat.* 1 ed. Bungay: Mcdonald and Evans Limited.

Davison, D. M., Miller, K. W. & Metheny, D. L., 1995. What Does Integration of Science and Mathematics Really Mean. School Science and Mathematics, 95(5), pp. 226-230.

Davidson, N. (1985). Small-Group Learning and Teaching in Mathematics. In: Slavin, R., Sharan, S., Kagan, S., Hertz-Lazarowitz, R., Webb, C., Schmuck, R. (eds) Learning to Cooperate, Cooperating to Learn. Springer, Boston, MA. https://doi.org/10.1007/978-1-4899-3650-9_8

Department of Basic Education , 2011. *Curriculum and Assessment policy statement: Further Education and Training phase..* Pretoria: s.n.

Department of Basic Education, 2014-19. *National Senior Certificate Examination Diagnostic Report.* Pretoria: Department of Basic Education.

Department of Basic Education, 2018. *National Senior Certificate 2018 Diagnostic Report.* Pretoria: s.n.

Dlamini, J. J., 2012. *Investigating the effect of context-based problem solving on the performance of learners.* Pretoria: University of South Africa.

Dimitrov, D. M. & Rumrill, P. D., 2003. Pretest-posttest designs and measurement of change. *Speaking of Research,* pp. 159-165.

Djudin, T., 2020. An Easy Way to Solve Problems of Physics by Using Metacognitive Strategies: A Quasy-Experimental Study on Prospective Teachers in Tanjungpura University-Indonesia. *Journal of Teaching and Teacher Education,* 8(1), pp. 19-27.

Dlamini, J. & Mogari, D., 2013. The effect of a group approach on the performance of high school mathematics learners. *Phythagoras,* 34(2), pp. 1-9.

Edwards, J. R. et al., 2008. National Healthcare Safety Network (NHSN) report, data summary for 2006 through 2007, issued November 2008. *American journal of infection control,* 36(9), pp. 609-626.

Erdal, B., Bagceci, B. & Cetin, B., 2012. The Effects of Social Constructivist Approach on the Learners' Problem Solving and Metacognitive Levels. *Journal of Social Sciences,* 8(3), pp. 343-349.

Everret, L. J., 1988. An alternative algebra for deriving equations of motion of flexible manipulators. *Journal of Robotic Sysytems.*

Frykholm, J. & Glasson, G., 2005. Connecting science and mathematics instruction: Pedagogical context knowlege for teachers.. *School Science and Mathematics,* 105(3), pp. 127-141.

Furner, J. M. & Kumar, D. D., 2007. The mathematics and science integration argument: a stand for teacher education.. *Eurasia Journal of Mathematics, Science & Technology Education,* 3(3), pp. 185-189.

Glatthorn, A. A., 1994. Constructivism: Implications for curriculum.. *International Journal of Educational Reform,* 3(4), pp. 449-445.

Govender, N., 2007. Physics student teachers' mix of understandings of algebraic sign convention in vector-kinematics: A phenomenographic perspective. *African Journal of Research in SMT Education,* 11(1), pp. 61-37.

Gruba, P. & Sondergaard, H., 2001. A Constructivist Approach to Communication Skills Instruction in Computer Science. *Computer Science Education,* 11(3), pp. 203-219.

Hake, R. R., 1997. Interactive-engagement vs traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics,* Volume 66, pp. 64-74.

Hake, R. R., 1998. *"Interactive engagement methods in introductory mechanics courses.*
[Online] Available at: http://carini.physics.indiana.edu/SDI/
[Accessed 5 November 2019].

Haney, J. J., Lumpe, A. T. & Czerniak, C. M., 2003. Constructivist Beliefs About the Science Classroom LearningEnvironment: Perspectives From Teachers, Administrators,Parents, Community Members, and Students. *School Science and Mathematics,* 103(8), pp. 366-377.

Ighomereho, P. O., 2005. *Students expressed usage of some mathematical concepts in senior secondary physics.* s.l.: Lagos State University.

Iwuanyanwu, P. N. & Ogunniyi, M. B., 2019. *Challenges facing pre-service teachers in developing conceptual resources needed to solve science problems..* Durban, SAARMSTE.

Jackson, J., Dukerich, L. & Hestenes, D., 2008. Modeling Instruction: An Effective Model for Science Education. 17(1), pp. 10-17.

Kirschner, F.C. (2009). United brains for complex learning: A cognitive load approach to collaborative learning efficiency. Unpublished doctoral dissertation. Interuniversity Centre for Educational Research, Open University, Maastricht, The Netherlands. Available from http://dspace.ou.nl/handle/1820/2391

Kiray, S. A., 2012. A new model for the integration of science and mathematics: The balance model. *Energy, Education Science and Techology Part B: Social and Educational Studies,* 4(3), pp. 1181-1196.

Koopman, O., 2017. Investigating How Science Teachers in South Africa Engage with all Three Levels of Representation in Selected Chemistry Topics. *African Journal of Research in Mathematics, Science and Technology Education,* 21(1), pp. 15-21.

Koopman, O. (2018). Science Education and Pedagogy in South Africa. New York; Peter Lang.

Kriek, J. & Grayson, D., 2009. A Holistic Professional Development model for South African Physical Science Teachers. *South African Journal of Education,* Volume 29, pp. 185-203.

Lederman, N. G. & Neiss, M. L., 1997. Integrated, interdisciplinary, or thematic instruction? Is this a question or is it questionable semantics?. *School Science and Mathematics,* 97(2), pp. 57-58.

Lederman, N. G. & Neiss, M. L., 1998. 5 Appless + 4 oranges=?. *School Science and Mathematics,* 98(6), pp. 281-284.

Lehman, J., 1994. Integrating science and mathematics: Perceptions of preservice and practicing elementary teachers.. *School Science and Mathematics,* 94(2), pp. 58-64.

Maree, C. E., 2021. *A STUDY OF PRE-SERVICE SCIENCE TEACHERS' PEDAGOGICAL USE OF MULTIPLE REPRESENTATIONS DURING LESSON PRESENTATIONS,* Stellenbosch: University of Stellenbosch.

Mason, T. C., 1997. Integrated curricula: Potential and problems.. *Journal of Teacher Education,* 47(4), pp. 263-270.

McDermott, L. C., Rosequist, M. L. & van Zee, E. H., 1987. Student difficulties in connecting graphs and physics: Examples from kinematics. *American Journal of Physics,* 55(6), pp. 503-513.

Meredith, D. C. & Marrongelle, K. A., 2008. How students use mathematical resources in an electrostatics context.. *American Journal of Physics,* Volume 76, pp. 570-578.

Obafemi, A. D., 2005. *A comparative analysis of attitudes towards physics in the University Demonstration and Unity secondary schools in Rivers State.* s.l.:University of Port Harcourt.

Ogunkunle , R. A. & Obafemi, D. T. A., 2013. Mathematics Abilities of Physics Students: Implication for the Application and Analysis of Sound Waves. *Journal of Education and Practice,* 4(24), pp. 94-100.

Owalabi, T., 2008. *Students' expressed mathematics errors in solving numerical problems in physics. In Udofia, N (Ed.).* Nigeria, Curriculum development in Science, Technology and Mathematics (STM) Education. Proceedings of the 49th Science Teachers' Association of Nigeria Conference. , pp. 259-261.

Palmquist, B. C., 2001. Assessing Motion Graphs. *The science teacher; research library,* 68(8), p. 75.

Phage, I. B., 2015. *An analysis of students' knowledge of graphs in mathematics and kinematics,* South Africa: North West Univeristy.

Phage, I. B., Lemmer, M. & Hitge, M., 2017. Probing Factors Infl uencing Students' Graph Comprehension Regarding Four Operations in Kinematics Graphs. *African Journal of Research in Mathematics, Science and Technology Education,* 21(2), pp. 200-2010.

Potgieter, M., Harding, M. & Engelbrecht, J., 2008. Transfer of algebraic and graphical thinking between mathematics and chemistry. *Journal of Research in Science Teaching,* Volume 45, pp. 197-218.

Qhobela, M. & Moru, E. K., 2011. Learning physics through argumentation at secondary school level in Lesotho: a feasible teaching strategy?. *African Journal of Research in MST Education,* 15(2), pp. 205-220.

Qhobela, M. & Moru, E. K., 2014. Understanding Challenges Phyisics Teachers Come Across as They Implement Learner-Centred Approaches in Lesotho. *African Journal of Research in Mathematics, Science and Technology Education,* 18(1), pp. 63-74.

Redish, E. F., 2005. *Problem Solving and The Use of Math in Physics Course.* New Dehli, In proceedings of the conference on world view on physics education: Focusing on change.

Redish, E. F. & Kuo, E., 2015. Language of physics, language of math: Disciplinary culture and dynamic epistemology. *Science and Education,* Volume 24, pp. 561-590.

Roebuck, K. L. & Warden, M. A., 1998. Searching for the center on the mathematics- science continuum. *School Science and Mathematics,* 98(6), pp. 328-333.

Study Up, 2009. *Mathematics and physics- math's relation to physics..* [Online] Available at: www.studyup.com/articles/careers/graduatecollegeloans.htm [Accessed 1 November 2019].

Thanormsuay, S., 2010. *Thai pre-engineering students, mathematical background and attitudes toward instruction..* Dublin, Ireland, European Applied Business Research (EABR) and European College Teaching & Learning (ETLC).

Thomas, L., 2020. *Quasi-Experimental Design | Definition, Types & Examples.* [Online] Available at: https://www.scribbr.com/methodology/quasi-experimental-design [Accessed 20 August 2021].

Unlu, Z. K., Domke, I. & Tufekci, A., 2015. An action research on teaching science through technology. *Procedia-Social and Behavioral Sciences,* Volume 186, pp. 46

Yackel, E., Cobb, P. & Terry, W., 1991. Small-Group Interactions as a Source of Learning Opportunities in Second-Grade Mathematics. *Journal for Research in Mathematics Education,* 22(5), pp. 390-408.

ADDENDUM A

MATHEMATICAL ABILITY TEST (MAT)

Algebraic Questions, for Grade 10, on simplifying, factoring, graphs, evaluating expressions and solving equations.

Question 1

1.1 1.1.1 Write 4×10^{-2} as a decimal.

1.1.2 Write 0.12×10^{-3} as a decimal.

1×2

1.2 Use the laws of exponents to simplify the following expressions:

1.2.1 $x^6 \times x^{-2} \div x^2$

1.1.2 $(3p)^q \times 3p^2$

1.2.3 $6^0 \div 12^2 \times 3^3$

1.1.4 $\dfrac{(-x^{-2}y)^2}{(-xy^3)^{-1}}$

3×4

Question 2

Remove brackets and simplify the following expressions:

2.1 $5a(a-3)$

2.2 $2x(x+4)-(3x+1)$

2.3 $(4m-1)(3m+2)$

2.4 (x + 3)(x - 3) - (-x - 9)

2×4

Question 3

Factorise the following expressions:

3.1 $15xy - 3y$

3.2 $\frac{1}{4}m^2 - 25$

3.3 $3x^2 - 8x + 4$

3.4 $2r^2 - 11r - 6$

2×4

Question 4

Check, by substitution, whether or not $x = -1$ is a solution to each of the following equations: (Show all your work)

4.1 $7+2(x-1)=3-4x$ 4.2 $(x-1)(x+1)=0$

4.3 $3x(x-1)^2=0$ 4.4 $\frac{-4x}{3}=\frac{1}{3}(4-x)$ 3×4

Question 5

5. Consider the data on the table below showing a relationship between x and y.

X	Y
0	-4
4	-20
-4	12
8	-36

5.1 Find an equation that best describes the relationship between x and y in this table. (3)

5.2 Plot an x vs y graph using the data set given on a piece of graph paper. (3)

Question 7

Solve for *x* in each of the following equations:

7.1 $7x-8=27$ 7.2 $3x-18=-3(x+7)$

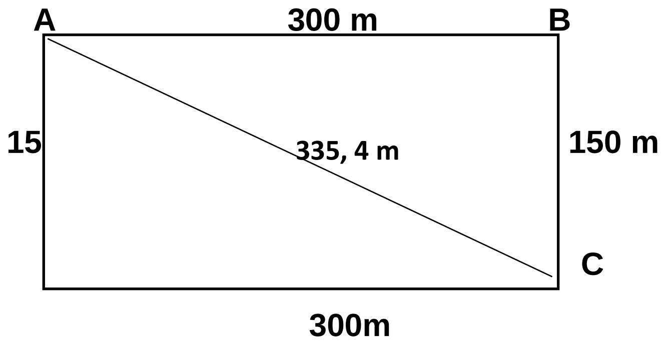
1× 2

[TOTAL: 50 MARKS]

ADDENDUM B

EQUATIONS OF MOTION ACHIEVEMENT TEST (EoMAT)

1. A boy takes 10 minutes to run around the perimeter of the school playing fields, as shown in the diagram below. He runs at a steady (constant) speed from A through B, C and D and back to A again.



For the circuit from A through B, C and D, and back to A, ….

1.1 Calculate his average speed. (4)

1.2 Determine his displacement. (2)

1.3 Calculate his average velocity. (2)

For the part of the circuit from A through B to C, …

1.4 write down his displacement (with reference to the line AB) (2)

1.5 calculate his average velocity from A to C. (3)

[13]

2. A racing car accelerates uniformly from 0 to 100 $km \cdot h^{-1}$ in 7,5 s.

2.1 Define the term "acceleration". (2)

2.2 Convert 100 $km \cdot h^{-1}$ to $m \cdot s^{-1}$. (2)

2.3Calculate the magnitude of the car's

acceleration. (3)

2.4 How far does the car travel during this time?

Show your calculation. (3)

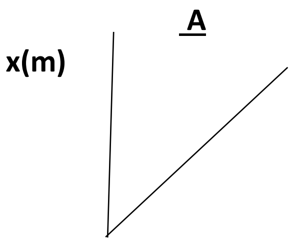
2.5 The driver applies the brakes and brings the car to a stop from 100 km·h−1 in 10 s.

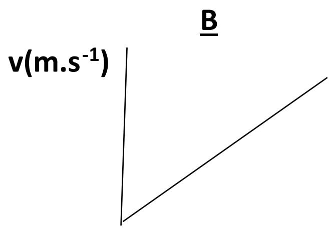
Calculate the car's acceleration during

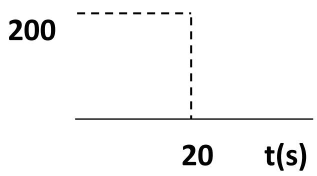
this 10 s. (4)

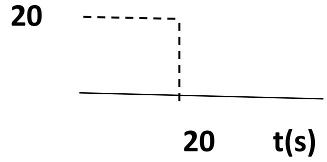
[14]

3. The two graphs, shown below, are plotted for two different vehicles (Vehicle A and Vehicle B). Study these two graphs and answer the questions which follow.





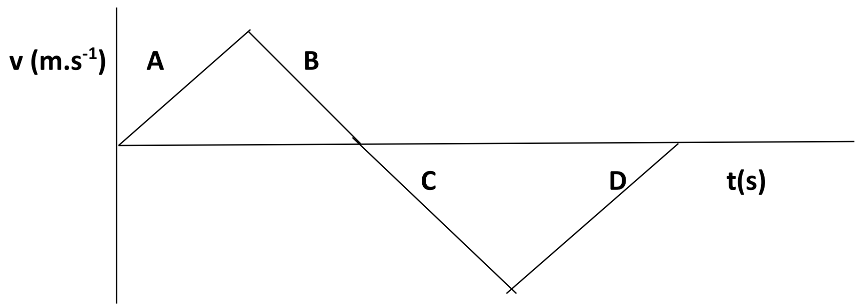




3.1 Describe how the motion of Vehicle A differs from that of Vehicle B. (2)

3.2 How do the displacements of the two vehicles differ after 20 seconds? Which vehicle has travelled further? Justify your answer with reference to the graphs. (4)

3.3. Study the following velocity-time graph of a toy car moving along a straight track.



Describe the motion of the car in terms of the magnitude of its velocity, and its direction of travel. Take the positive direction to represent "forward". Copy the table below and write in your answers for each stage of the car's journey.

	VELOCITY IS INCREASING/ DECREASING	DIRECTION OF MOTION IS TOWARDS/ AWAY FROM THE OBSERVER
A		
B		
D		
C		

(8)

[14]

4. A car accelerates uniformly from a stop street along a straight road, covering the following distances in 10 s as shown in the Table below.

ELAPSED TIME (t) IN SECONDS	**2**	**4**	**6**	**8**	**10**

DISTANCE FROM STARTING POSITION (m)	10	18	24	28	30

4.1 Plot a displacement – time graph of the car's motion (on a piece of graph paper). (6)

4.2.1 Describe the shape of the graph. (1)

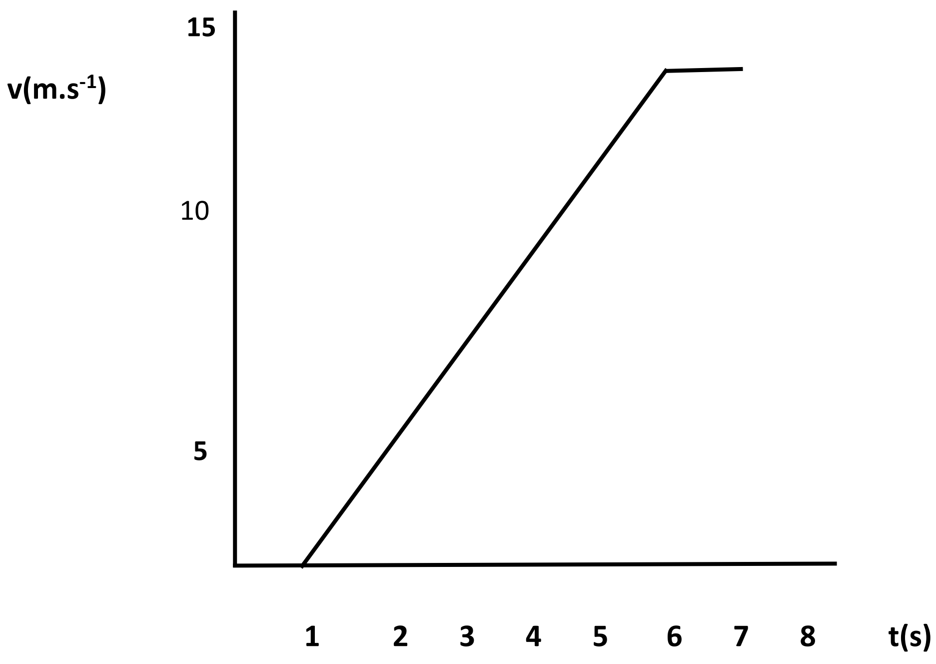
4.2.2 Describe the motion of the car. (2)

4.3 Use the graph to determine the magnitude of the average velocity of the car. (3)

4.4 Use the graph to determine the magnitude of the instantaneous velocity of the car at 3 s. (3)

[15]

5. A driver stops his car at the traffic light when it turns red. The graph of the car's velocity against time shows its motion for 8 s from the time the traffic light turns green.



5.1 The short time interval between the traffic light turning green (for GO) and the driver responding to the signal, is known as "the driver's reaction time".

5.1.1 How long does the driver take to respond when the traffic light changing to green? 1 (1)

5.1.2 Give TWO factors that can affect the reaction time of a driver. (2)

5.2 Determine the maximum speed of the car. (1)

5.3 Use the graph to calculate the average acceleration of the car. (3)

5.4 Use the graph to determine the displacement of the car over this 8 s. (3)

5.5 Calculate the average velocity of the car over 8 s. (4)

[14]

[TOTAL:70 MARKS]

ADDENDUM C

RESULTS OF THE EoMAT and MAT FROM THE EXPERIMENTAL (Group 1) and CONTROL GROUPS (Group 2)

Group	Learners	Pre-test (MAT)	Pre-test (EoMAT)	Post-test (EoMAT)

1	1	45	50	55
1	2	42	48	54
1	3	40	38	43
1	4	40	36	37
1	5	40	32	33
1	6	38	36	40
1	7	35	29	30
1	8	35	41	43
1	9	35	43	42
1	10	33	32	33
1	11	33	34	33
1	12	33	34	25
1	13	30	36	38
1	14	30	35	36
1	15	30	35	35
1	16	30	29	34
1	17	29	20	23
1	18	27	25	30

2	19	27	25	27
2	20	27	34	33
2	21	26	24	20
2	22	25	31	32
2	23	25	21	29
2	24	25	20	21
2	25	24	32	30
2	26	20	33	31
2	27	20	25	25
2	28	19	21	22
2	29	19	20	21
2	30	18	15	16
2	31	18	27	20
2	32	18	25	26
2	33	17	17	15
2	34	16	23	20
2	35	15	24	23
2	36	10	18	14

ADDENDUM D

EXAMPLE OF A LESSON PLAN FOR THE CONTROL GROUP

INTRODUCTION

Many learners have difficulty organising data when asked to solve a problem. They are unsure of which quantity is the initial or final velocity, and they may not understand that acceleration is negative when an object is slowing down.

CONCEPT EXPLANATION AND CLARIFICATION:

1. Organising data to solve problems using the equations of motion. Encourage learners to write down the list of variables, and then to read through the question collecting the values for these variables. There should be at least three values mentioned in the question, so that they can solve for the 4th and/or 5th variables. For example: A car accelerates uniformly along a straight level road increasing its speed from 10 $m{\cdot}s^{-1}$ to 30 $m{\cdot}s^{-1}$ in 25s.

Calculate:

a) the acceleration of the car, and b) the

distance travelled during these 25 s.

The learner will be able to find these three values, and then proceed to use the

appropriate equation of motion.

$V_i = 10\ m{\cdot}s^{-1}$

$V_f = 30\ m{\cdot}s^{-1}$

a = ?

$\Delta t = 25$ s

$\Delta x = ?$

2. Choosing an appropriate equation of motion to solve a problem.

Referring to the example shown above, we note that the initial velocity, final velocity and time are values which are given in this problem.

a) The acceleration of the car must be calculated.

   Possible equations are:

   $V_f = V_i + at$

   $V_f{}^2 = V_i{}^2 + 2a\Delta x$

   $\Delta x = Vi\ \Delta t + ½\ a\Delta t^2$

However, we must use the first of these equations because we have sufficient data to calculate an answer.

$V_f = V_i + at$

30 = 10 + a (25)

$a = \frac{(30 - 10)}{25} = 0,8\ m{\cdot}s^{-2}$ forward

(b) The displacement (distance travelled) must be calculated.

Possible equations are:

$$V_f^{\,2} = V_i^{\,2} + 2a\Delta x$$

$$\Delta x = Vi\ \Delta t + ½\ a\Delta t$$

$$\Delta x = \frac{(Vi + Vf)}{2}\ \Delta t$$

Any of these equations will suffice. We now know the value of the acceleration so we have sufficient data to use any of these equations.

However, if we hadn't already calculated the acceleration, we could use the last of these equations, using the data which was given in the question.

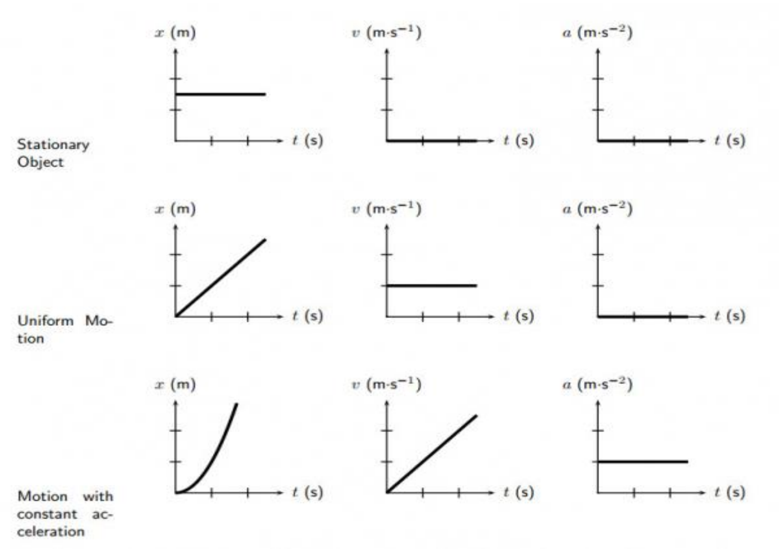
$$\Delta x = \frac{(Vi + Vf)}{2}\ \Delta t$$

$$\Delta x = \frac{(10 + 30)}{2}\ \text{x}\ 25$$

$$= 500\text{m}$$

3. Describing motion using graphs of motion

   Three different graphs of motion can be drawn: position-time, velocity-time and acceleration-time.



CORRESPONDING LESSON PLAN FOR THE EXPERIMENTAL GROUP

INTRODUCTION

Many learners have difficulty organising data when asked to solve a problem. They are unsure of which quantity is the initial or final velocity, and they may not understand that acceleration is negative when an object is slowing down. They struggle how to select the right equation of motions given a particular scenario, mathematically manipulating the equations, understanding the significance of vector sign convention, conversion to proper SI units before substitution during calculations and finally relating the equations and their corresponding graphs to mathematical concepts and graphs.

CONCEPT EXPLANATION AND CLARIFICATION:

1. Organising data to solve problems using the equations of motion. Encourage learners to write down the list of variables, and then to read through the question collecting the values for these variables. There should be at least three values mentioned in the question, so that they can solve for the 4th and/or 5th variables. For example: A car accelerates uniformly along a straight level road increasing its speed from 100 $km \cdot h^{-1}$ to 300 $km \cdot h^{-1}$ in 25s.

Calculate:

a) the acceleration of the car, and

b) the distance travelled during these 25s.

The learner will be able to find these three values, and then proceed to use the appropriate equation of motion.

$V_i = 100\ km \cdot h^{-1}$

$V_f = 300\ m \cdot h^{-1}$

$a = ?$

$\Delta t = 25\ s$

$\Delta x = ?$

2. Choosing an appropriate equation of motion to solve a problem.

Referring to the example shown above, we note that the initial velocity, final velocity, and time are values which are given in this problem.

(b) The acceleration of the car must be calculated.

Possible equations are:

$V_f = V_i + a\Delta t$

corresponds to the mathematical expression of a straight-line graph (y = mx + c)

$V_f^{\ 2} = V_i^{\ 2} + 2a\Delta x$

$\Delta x = Vi\ \Delta t + \frac{1}{2} a\Delta t^{\ 2}$

corresponds to the mathematical expression of a parabolic graph $y = ax^2 + bx + c$

However, we must use the first of these equations because we have sufficient data to calculate an answer, but first we need convert velocity values to the proper SI units (km·h^{-1} to m·s^{-1})

V_i = 100 km·h^{-1} = $\frac{100\ km}{1\ h}$ x $\frac{1000\ m}{1\ km}$x $\frac{1\ h}{60\ min}$ x $\frac{1\ min}{60s}$ = 27,78 m·s^{-1}

V_f = 300 km·h^{-1} = $\frac{300\ km}{1\ h}$ x $\frac{1000\ m}{1\ km}$x $\frac{1\ h}{60\ min}$ x $\frac{1\ min}{60s}$ = 83.33 m·s^{-1}

$V_f = V_i + at$

30 = 10 + a (25)

Making acceleration, 'a', the subject of the formula

a = $\frac{(83.33 - 27.78)}{25}$ = 2.22 m·s^{-2} forward

(b) The displacement (distance travelled) must be calculated.

Possible equations are:

$V_f{}^2 = V_i{}^2 + 2a\Delta x$

$\Delta x = Vi\ \Delta t + ½\ a\Delta t$

$\Delta x = \frac{(Vi + Vf)}{2}\ \Delta t$

Any of these equations will suffice. We now know the value of the acceleration so we have sufficient data to use any of these equations.

However, if we hadn't already calculated the acceleration, we could use the last of these equations, using the data which was given in the question.

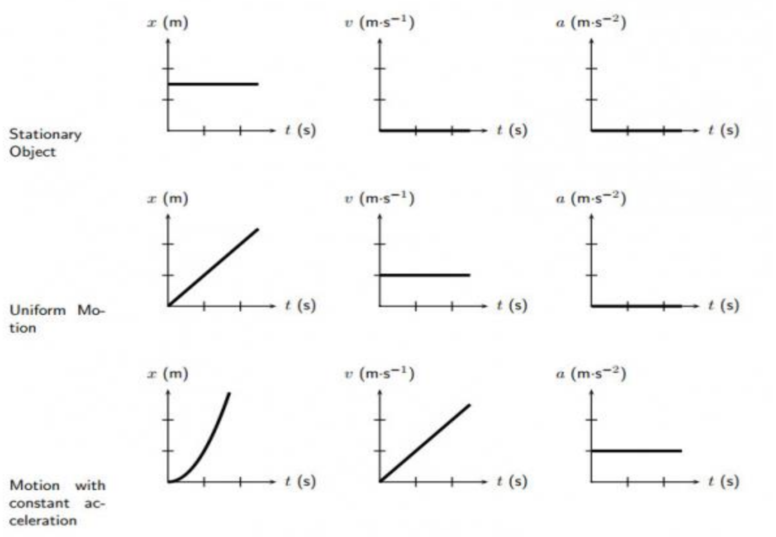
$\Delta x = \frac{(Vi + Vf)}{2}\ \Delta t$

$\Delta x = \frac{(27.78 + 83.33)}{2}$ x 25

= 1389.50 m

3. Describing motion using graphs of motion

Three different graphs of motion can be drawn: position-time, velocity-time and acceleration-time.



The first question that needs to be asked concerning any graph of motion is: "Which variable is on the y-axis?" In other words, which particular graph is this?

Thereafter, take note of the shape of the graph:

- Is it a straight-line graph, parallel to the x-axis?
- Or is it a straight-line graph passing through the origin?
- Is the graph curved, like a parabola?

4. The velocity-time graph is linked to the position-time graph in two different ways:

a) The gradient of the position-time graph at any point on the graph gives the magnitude of the velocity.

As you can see from the graphs of uniform velocity, the steeper the gradient of the straight-line graph the greater the value of the constant velocity.

b) The area under the velocity-time graph gives the displacement (change in position) of the object.

ADDENDUM E

PEARSON PRODUCT-MOMENT RESULTS

X Values

∑ = 994

Mean = 27.611

∑(X - Mx)2 = SSx = 2648.556

Y Values

∑ = 1068

Mean = 29.667

∑(Y - My)2 = SSy = 2534

X and Y Combined

N = 36

∑(X - Mx)(Y - My) = 2072.333

R Calculation

r = ∑((X - My)(Y - Mx)) / √((SSx)(SSy))

r = 2072.333 / √((2648.556)(2534)) = 0.7999

Meta Numerics (cross-check)

r = 0.7999

The P-Value is < .00001. The result is significant at p < .05.

Key

X: X Values

Y: Y Values

Mx: Mean of X Values

My: Mean of Y Values

X - Mx & Y - My: Deviation scores

(X - Mx)2 & (Y - My)2: Deviation Squared

(X - Mx)(Y - My): Product of Deviation Scores

ADDENDUM F

INDEPENDENT T-TEST RESULTS

Group 1 (Experimental)

N_1: 18

df_1 = N - 1 = 18 - 1 = 17

M_1: 36.89

SS_1: 1219.78

$s^2_1 = SS_1/(N - 1) = 1219.78/(18-1) = 71.75$

Group 2 (Control)

N_2: 18

df_2 = N - 1 = 18 - 1 = 17

M_2:	23.61	$s^2_2 = SS_2/(N - 1) = 582.28/(18-1) = 34.25$	
SS_2:	582.28		

T-value **Calculation**

$s^2_p = ((df_1/(df_1 + df_2)) * s^2_1) + ((df_2/(df_2 + df_2)) * s^2_2) = ((17/34) * 71.75) + ((17/34) * 34.25) = 53$

$s^2_{M1} = s^2_p/N_1 =$	53/18	=	2.94
$s^2_{M2} = s^2_p/N_2 =$	53/18	=	2.94

$t = (M_1 - M_2)/\sqrt{}(s^2_{M1} + s^2_{M2}) = 13.28/\sqrt{}5.89 = 5.47$

The t-value is 5.47145. The p-value is < .00001. The result is significant at $p < .05$.

ADDENDUM G

ETHICAL CLEARANCE FOR THE STUDY

Cape Peninsula University of Technology

Cape Peninsula University of Technology

Private Bag X8, Wellington, 7654
Jan van Riebeeck Street, Wellington, 7654
Tel: +27 21 864 5200

P.O. Box 652, Cape Town, 8000
Highbury Road, Mowbray
Tel: +27 21 680 1500

FACULTY OF EDUCATION

On the 27th of July 2021 the Chairperson of the Faculty of Education Ethics Committee of the Cape Peninsula University of Technology granted ethics approval **(EFEC 2-7/2021)** to Z Mabangula for research activities related to a M. Ed degree.

Title:	The relation between Grade 10 learners' mathematical knowledge and their understanding of equations of motion in Physical Science

Comments:

The EFEC unconditionally grants ethical clearance for this study. This clearance is valid until 31st December 2024. Permission is granted to conduct research within the Faculty of Education only. Research activities are restricted to those details in the research project as outlined by the Ethics application. Any changes wrought to the described study must be reported to the Ethics committee immediately.

Date: 4th of August 2021

Dr Candice Livingston

Research coordinator (Wellington) and Chair of the Education Faculty Ethics committee

Faculty of Education

ADDENDUM H

Ethics informed consent form for the study

Faculty of Education
Ethics informed consent form

CONSENT TO PARTICIPATE IN A RESEARCH STUDY

Category of Participants (tick as appropriate):

Principals		*Teachers*		*Parents*		*Lecturers*		*Students*	X
Other (specify)									

You are kindly invited to participate in a research study being conducted by Mr Z. Mabangula from the Cape Peninsula University of Technology. The findings of this study will contribute towards (tick as appropriate):

An undergraduate project		*A conference paper*	
An Honours project		*A published journal article*	
A Masters/doctoral thesis	X	*A published report*	

Selection criteria

You have been selected as a potential research participant in this study as you meet the criteria as set out in my summary below. The main criteria are (i) you must be a grade 10 learner and (ii) you must attend school in a historically disadvantaged school. I am also grateful that you volunteer to participate in this study.

The information below gives details about the study to help you decide whether you would want to participate.

Title of the research:

The relation between Grade 10 learners' mathematical knowledge and their understanding of equations of motion in Physical Science.

A brief explanation of what the research involves:

This study seeks to determine the relationship between Grade 10 learners' mathematical knowledge and its applications in solving equations of motion in physical sciences. The literature reports that this topic is a huge challenge to learners in the FET phase. Propelled by these research findings the researcher will recruit 100 Grade 10 physical science learners to investigate the following main research question: What is the relation between Grade 10 learners' mathematical competency and their understanding of Equations of Motion in Physical Sciences?

The study will adopt a mixed-method approach in which both quantitative and qualitative data will be collected. Quantitative data collection will proceed via pre- and post-tests, using standardized Grade 10 Equations of Motion Achievement Test (EoMAT) and Mathematics Ability test (MAT). From the qualitative side the study will employ semi-structured face to face interviews with 10 research participants to provide deeper meaning to the quantitative data. The researcher firmly believes that the answers to this question can help the science education community to improve the quality of teaching and learning in schools.

Why is this research important?

The main aim of the study is to establish the relation between Grade 10 learners' mathematical competency and their understanding of Equations of Motion in Physical Sciences. The study also seeks to establish the qualitative reasoning that is often overlooked by both teachers and students/learners when solving mechanics problems because in research, the opportunity to engage in conversations has been shown to be an effective instructional tool for solving all kinds of problems in science. The knowledge that will eminate from this study will add to rich repository of existing knowledge on Grade 10 learners understanding of equations of motions and how mathematical competencies can add to the many challenges Grade 10 learners face.

Benefits of research

The main benefits of this study are:

Expand knowledge and understanding of the relation grade 10 learners relation between mathematical competencies and solving problems in physical sciences.

Procedures

- The 100 Grade 10 research participants recruited for this study will be divided into two groups. A control (50 learners) and an experimental (50 learners).

To the experimental group:

- A pre-test will be administered to provide baseline data. This will be followed by an intervention strategy after which they will be given a post-test.
- For the intervention the learners will be subjected to a four-week teaching programme to make explicit the Mathematics that underpins the Science Grade 10 equations of motion topic using a learner-centred strategy.
- These lessons planned for this group by the science teacher, who is also the researcher, will not only include the required science content and worksheets but the mathematics that is embedded in equations of motions.
- Over the 4-week period, 4 hours a week will be dedicated to teaching with each lesson approximately 50 minutes in length. This will be done without any interference with the school programme. It will be offered after school.

To the control group:

- A pre-test will also be issued to the control group at the beginning of the study and then they will be taught in a conventional way the topic of equations of motion over a period of 4 weeks, conducting the lessons for 4 hours a week and each lesson will be about 50 minutes long a day.
- The lessons will be planned by a science teacher.
  Then after that a post-test will be issued.

From the qualitative angle the study will employ semi-structured interviews. Five learners (N=10) from each of the participating groups will be purposively sampled for the interviews to provide their opinions on the style of teaching they received in their respective groups. These interviews will be conducted after all quantitative data collection has taken place (after the post-test has been written). After carefully evaluating the results of the post-test, the researcher will choose from these 10 perspective interviewees from the participating grade 10 leaners, ranging from poor, satisfactory, good, and outstanding. These interviews will be conducted at the same venues the quantitative data will have been collected, which is at the chosen schools, after normal school hours and each interview will be about 45 minutes long. This exercise is an endeavour to gain a deeper understanding on issues related to how the learners think, as the pre-test and post-test alone are not enough to provide such information.

Participation and Withdrawal

The researcher will explain to the potential participants that participation in the research was voluntary and that he or she must feel free to withdraw from participation in the study at any time. Furthermore, he will explain to the participants that they can refuse to answer certain questions or to take part in any interviews without fear of being reprimanded. If the need arise the researcher can also withdraw any participant from the study.

The researcher will also emphasize the importance of the participants to follow procedures laid out for them should they agree to participate otherwise the study will be compromised and then time and opportunity will be lost.

Anonymity

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Anonymity will be maintained by means of allocating a numbers/letters/pseudonyms for the schools and the participants who will be involved in the interviews (e.g., school A, B, C, etc.). No raw data will be published, information will be published, only after it has been analysed and as part of an overall study.

Confidentiality

All data collected will be Excel and Word password protected and that the computer is password protected and that all answer scripts and interview hard copy documents will be locked away in the primary researcher's office.

The content of questionnaires or any other data will not be published, nor will it be given to any third party for any other form of research without the express permission of the participants.

After the data has been used it will be destroyed once the university quality assurance requirements have been met.

The results of this study will be published in an M. Ed dissertation. An article submission will be made to at least one DoE accredited article and at least one conference paper will be produced. Copies of the articles can be made available if requested.

Potential risks, discomforts, or inconveniences

The researcher believes that the study is low risk as it will involve:

- A study of a social setting that is not controversial.
- Post-hoc analysis of large sample of learners of test papers where anonymity of learners is assured.
- Ordinary adolescent participants from the township areas.
- Little potential for discomfort or inconvenience on the part of participants; where such potential does exist, the predicted discomfort or inconvenience would be minor.

What will happen to the data when the study is completed?

Once the necessary data is collected, it will be used to complete a paper that is publishable. A paper will also be written to present at a conference. Once the study is completed an all the university requirements have been met, the data will be destroyed.

Both you and your parent/ legal guardian are required to kindly complete the table below and give your signatures after that before participating in the research.

Tick the appropriate column		
Statement	Yes	No
1. I understand the purpose of the research.		
2. I understand what the research requires of me.		
3. I volunteer to take part in the research.		
4. I know that I can withdraw at any time.		
5. I understand that there will not be any form of discrimination against me as a result of my participation or non-participation.		
6. Comment:		

Please sign the consent form. You will be given a copy of this form on request.

Signature of participant: Signature of Parent/Legal Guardian:	Date: Date:

Researchers

	Name:	Surname:	Contact details:
1.	Zingisa	Mabangula	0632767613
2.			
3.			

Contact person: Zingisa Mabangula	
Contact number: 0632767613	Email: marzgoni@gmail.com

LIST OF ACRONYMS AND ABBREVIATIONS

Further Education and Training (FET)

Curriculum Assessment and Policy Statement (CAPS)

Western Cape Education Department (WCED)

Subject Matter Knowledge (SMK)

Pedagogical Content Knowledge (PCK)

Mathematics Ability Test (MAT) and Equations of Motion Achievement Test (EoMAT)

Science-centered Mathematics-Assisted Integration (SCMAI)

Science-centered Mathematics-Assisted Integration (SCMAI)