UNDERSTANDING THE EFFECT OF ROBOTICS AS AN INTERVENTION STRATEGY IN A TECHNICAL SCIENCES CLASS

by

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DECLARATION

I, Katlego Maphiri Rebecca Leshabane (11325390), declare that this Master's dissertation entitled: "Understanding the effect of Robotics as an intervention strategy in a Technical Sciences class" which I hereby submit for the degree Magister Educationis at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

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- Compliance with approved research protocol,
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Dedication

I dedicate this research to my late father, Sekodi John Leshabane, who affirmed my love for education in his wise words “Monna ke thuto”.

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To God Almighty, thank You for providing the strength to endure and see the research to completion. It is You who provided the wisdom and the grace and the will to persevere.

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ABSTRACT

In this study, the use of robotics was explored in a Grade 12 Technical Sciences class, to further understand it as an emerging pedagogy that allows learners to apply creative thinking and produce innovative solutions to problems in Newton's Second law of motion. The study's conceptual framework was underpinned by constructivism, constructionism and the Cognitive Refinement Instructional Approach (CRIA), which supports the notion that through assimilation and accommodation, Lego Mindstorms robotics tools can be used as manipulatives to develop new knowledge.

The learners participating in this mixed-method procedure of enquiry were randomly assigned to an experimental group (n = 21) that took part in the robotics intervention and a control group (n = 21) that continued with conventional extra classes. It was evident in the qualitative results that learner's knowledge improved regarding the concepts of acceleration and net force, but misconceptions persisted in the concepts of frictional force and tension force. In the analysis of the quantitative results, the independent-samples t-test showed that there was a significant difference in the post-test scores between the control group (M= 3.19, SD= 1.16) and experimental group (M=4.57, SD= 1.43); $t(40)= 3.42$, $p = 0.001$. The study found that robotics does have a significant effect on the academic test scores of Technical Sciences learners than the traditional intervention in Newton's Second Law. The scientific merit and significance of this study will contribute to teaching methods and learning of science in the technical-academic schooling stream.

Key Terms:

LEGO Mindstorms, Educational robotics, Cognitive Refinement Instructional Approach, constructivism.

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LIST OF ABBREVIATIONS

DBE	Department of Basic Education
CAPS	Curriculum and Assessment Policy Statement
CRIA	Cognitive Refinement Instructional Approach
EV3	Evolution 3 (Lego Mindstorms)
FET	Further Education and Training
ICT	Information and Communication Technology
LTSM	Learning Teaching and Support Material
NQF	National Qualifications Framework
NSC	National Senior Certificate
PAT	Practical Assessment Task
SBA	School-based Assessment
SPSS	Statistical Package for Social Sciences
STEM	Science Technology Engineering and Mathematics

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1 CHAPTER ONE: GENERAL ORIENTATION

1.1 INTRODUCTION

Science, Technology, Engineering and Mathematics (STEM) education is necessary for the future of South Africans and needs to be taught from early schooling irrespective of the socioeconomic status (Pols, 2019). An increasing body of evidence globally supports the educational benefits of studying robotics education at all levels of education, particularly through integrated STEM curricula that include technology and engineering skills, (Wright, et al., 2018). A study by Lopez-Belmonte, Segura-Robles, Moreno-Guerrero, & Parra-Gonzalez (2021) systematically reviewed international literature on robotics in education. In the said study a large body of evidence purports that Robotics has become a major topic in today's education, with an increase in the number of educational programs incorporating this dimension into their curricula in recent years, especially in developed countries.

A background paper for the MasterCard Foundation, which sought to investigate STEM and Information and Communication Technology (ICT) in Sub-Saharan Africa found that although South Africa's education policies have been reviewed since 1994, the way that learners are taught has however remained the same (Barett, Gardner, Joubert, & Tikly, 2019). As technology is becoming more prevalent in our society, the opportunity and necessity to integrate technology-driven methodologies into ways of teaching, are growing. One approach, especially in science education, is the introduction and use of educational robotics. Robotics education involves designing, building, and programming a robot while learning. This unique education curriculum provides theoretical knowledge and practical implementation in STEM basics while helping learners develop critical thinking and team-building skills, and possibly even presentation skills. Furthermore, (Jung & Won, 2018) establish that in many countries robotics educational applications can be used in a much broader range of topics by incorporating robotics curricula into the targeted subjects' existing curricula, such as mathematics, languages, music, and art. The goals of robotics education can be achieved by using robotics kits, such as LEGO MINDSTORMS®, designed by well-known toy manufacturer LEGO®, to demonstrate scientific principles in a fun and accessible approach; merging experiments that form scientific perceptions with methods that capture the imagination.
The background of the study will be provided in this chapter, including a narrative of the research study design. The discussion will then be followed by a description of the implementation process for the robotics intervention in Technical Sciences in a South African classroom in a school that is classified as a quintile 2 school. In South Africa, funding is provided according to the ranking of a school from quintile 1 to quintile 5, with quintile 1 schools

requiring the most funding. A school at quintile level 2 has limited resources, the learners are provided with a meal a day by the nutrition programme, and the funding received (norms and standards) typically reflects the high unemployment, low-income social-economic status and low level of education in the surrounding community that the school is situated in (van Dyk & White, 2019).

1.2 BACKGROUND

The researcher undertakes that the global position of robotics in education must be established. A scientific mapping of literature and a systematic review of robotics in education by Jung & Won (2018) and Lopez-Belmonte et. al., (2021) show that the use of robotics in education aids in the growth of critical thought, psychomotor skills, and problem-solving abilities in students, as well as encouraging practical learning. The 2017 NSC examination diagnostic report purports that in STEM-related subjects, the performance of candidates was better in items of lower cognitive order, or items requiring lower-order thinking skills, (Department of Basic Education South Africa, 2017). Questions that required higher cognitive demand, such as analytical skills, problem-solving and critical skills were poorly attempted. Newton's Second Law of Motion is part of the Technical Sciences in the South African National Curriculum, also referred to as the Curriculum and Assessment Policy (CAPS). The 2017 diagnostic report found that Grade 11 concepts are poorly understood, and suggests that learners must be afforded the opportunity of problem-solving involving Newton's second law in different contexts, (Department of Basic Education South Africa, 2017). It is with this background that a gap was identified in the researcher's own teaching experience in an under-resourced public school where the pedagogy was transmissivity and textbook-based.

1.3 PROBLEM STATEMENT AND RATIONALE

According to ORT South Africa (2017), robotics is becoming more popular and is an emerging technology used for pedagogical purposes as many countries all over the world include robotics in their school curriculum to equip children for a digital future. South African learners are being left behind with our schooling system struggling just to keep up with the current curriculum in mathematics and science (ORT South Africa, 2017), and quite a few private schools and public schools that can afford robotics equipment have recently been using robotics to teach (Admire, 2019). The National Curriculum Statement Grades R–12 is underpinned by the visionary principle of producing critical thinkers and decision-makers, a goal the researcher in this study proposes might be accelerated by the use of robotics. The application of robotics includes activities that are an important aspect in teaching and learning science, as they not only involve the mind but also require the learner to be an active participant in the learning process. The current South African curriculum partially includes this aspect, and the Department of Basic Education (DBE) has only recently announced that coding and robotics would be introduced in schools with a new curriculum to be implemented in 2020 (Admire, 2019).

Robotics provides a fun, yet a challenging method for kids to apply STEM concepts as it encourages critical reasoning, problem-solving, creativity and teamwork (Afari & Khine, 2017; Eguchi, 2014). Possibly more convincingly, learners are introduced to a deeper understanding of how the technology works, preparing them for a future that will be more technologically complex. Robotics can be helpful in education because students might find it tangible and also encourage them to create and innovate. Coffman (2009) states that one of the key factors that enhance student motivation, student performance and their quality of work is the use of technology integration in the classroom. Technology engages and motivates learners as it not only appeals to the visual aesthetics but also the auditory and kinaesthetic senses. It is important that educators effectively align technology to what is to be learned for the learning activity to be successful. Higgins, Xiao and Katsipataki (2012, p. 15) emphasise that "it is, therefore, the pedagogy of the application of technology in the classroom which is important: the *how* rather than the *what*." Technology should not replace the teacher, but be an aid to achieve learning.

Robotics has special characteristics: it is essentially multidisciplinary, which allows collaboration and immersion into diverse themes when designing a learning activity. Different stakeholders can be involved in formal and non-formal learning settings, which are closely linked to the introduction of innovations in organisations and schools, and thus Merden et al. (2017) conclude that many learning opportunities are possible because it is a tangible and hands-on learning approach.

1.4 PURPOSE OF THE STUDY AND RESEARCH QUESTIONS

In this study, the researcher used robotics in a Technical Sciences class to see whether there will be a difference in the test scores of learners in the mechanics topic, in particular, regarding Newton's second law of motion. The primary goal was to compare the test scores of Grade 12 learners who participated in a robotics intervention, to those that did not participate in the intervention and attended the traditional extra lessons intervention.

The research study sought to answer the following research questions:

<u>Main question</u>

What is the effect of the robotics intervention in Newton's second law of motion in Technical Sciences?

Secondary Questions

1. What is the baseline knowledge about Newton's second law of Grade 12 Technical Sciences learners?
2. What is the knowledge about Newton's second law of the control group and experimental group after the intervention?
3. What is the difference between the outcomes of an assessment about Newton's second law of the experimental group and the control group after the intervention?

1.5 KEY THEORETICAL CONCEPTS

1.5.1 Constructivism

In this research study, the term constructivism is derived from Piaget's constructivism theory that emphasises the construction of learning in the mind by the learner (Papert, 1980). The learner is at the centre of the process and interacts with objects and activities in different contexts to enhance their understanding of the particular setting, event or object. In constructivism, the learner is an active participant that conceptualizes his/her solution to problems (Papert, 1980).

1.5.2 Constructionism:

The hands-on aspect of constructivism is expanded in the theory of constructionism, whereby a learner physically interacts with and uses his/her kinaesthetic abilities to construct artefacts (Papert, 1980). The product/object that is constructed is tangible and meaningful to the learner and is a physical representation of the learning that has occurred and has been enabled by the learner who is at the centre of the process. Papavlasopoulou et al. (2019) posit that such artefacts created are further "thinking tools" for developing critical thinking and problem-solving.

1.5.3 Lego Mindstorms:

In his book titled "Mindstorms: Children, computers and powerful ideas", Seymour Papert (1980) introduced the educational research world to his studies on Lego Mindstorms at the MIT Media Laboratory. Lego Mindstorms are construction kits that consist of programmable robotics Lego pieces and allows learners to build and program their robots. Learners are immersed in the application of constructionism and constructivism theories by investigating scientific problems and building a physical, tangible model to use as part of the solution. There are many different types of robotics kits and brands. Still, for the purpose of this study, the researcher chose Lego Mindstorms because it is one of the few brands that allow a learner to be a full participant in the design and building process of the robot. The Lego Mindstorms kits are also easy to deconstruct and program that make it suitable for the present study.

1.5.4 National curriculum

The national curriculum is the South African National Curriculum, as determined by the Minister of Basic Education, with all the subjects listed on the National Curriculum Statement for Grades R–12. The policy encompasses the National Curriculum and Assessment Policy Statement (CAPS) as introduced by the DBE, which is inclusive of a comprehensive policy document that is a blueprint for all educators on what should be taught and assessed, (Department of Basic Education South Africa, 2019).

1.5.5 Technical Sciences

Technical Sciences is an elective subject that is part of the national curriculum, in the CAPS in the further education and training (FET) phase offered to Grades 10 to 12 learners, (DBE, 2014). The subject is aimed at supporting learners in mechanical, electrical and civil technology and is offered at Technical High Schools. Technical Sciences learners will be able to articulate on occupational, vocational and some academic technology courses at Universities of Technology.

1.6 HYPOTHESIS

Null hypothesis one (H0): There is no significant difference in the test results of learners who participate in the robotics intervention program and those who do not participate in the robotics.

Alternate hypothesis one (H1): There is a significant difference in the test results of learners who participate in the robotics intervention program and those who do not participate in the robotics.

1.7 PARADIGMATIC ASSUMPTIONS

In this study, the researcher followed a pragmatism approach, which is an approach to philosophy which holds that the truth or meaning of a practical statement is to be measured by its practical consequence, (Adeleye, 2017). Pragmatists strike a balance between the teacher being the centre of the learning activity, and each student should be able to contribute their ideas during learning activities. In the researcher’s view, the potential value of this particular paradigm is that it supports the researcher’s view that education is a lesson learnt from experience that is productive and not limiting. Epistemology is the branch of philosophy concerned with the origin, reliability and criterion of knowledge. The nature of knowledge is dynamic: always changing according to times, places and situations, (Adeleye, 2017). Magrini

(2009) proposes that knowledge arises between the relationship of the student and her environment, as it originates in the student's distinctive experiences and holds a genuine realistic value in both the life of the students and their community. Ontology is the study of what reality is. Pragmatists believe in the constant negotiation and re-interpretation of truth, and therefore the method that solves the problem will always be superlative (Patel, 2015).

1.8 RESEARCH DESIGN AND METHODOLOGY

The theoretical paradigm initiated the need for a mixed-method approach to the study. This mixed-method approach consisted of an embedded quasi-experimental design comprising a qualitative questionnaire embedded within the quasi-experimental strategy. The quasi-experimental research design involves testing hypotheses on selected groups, without any random pre-selection procedures (Shuttleworth, 2008). The effectiveness of the intervention was determined through a quasi-experimental study that included a pre-test and post-test with two groups. The two groups were randomly assigned to an experimental group that took part in the robotics intervention, and a control group who did not participate in the robotics intervention but took part in the traditional extra classes. The control group did not have access to the robotics kit or activities designed, until after the completion of the data collection process. This was not unethical as the control group learners were not deprived of any part of the prescribed curriculum in their school. The experimental group participated in the robotics program every day for two hours over three weeks. A pre-test was given to each group before the beginning of the intervention. After both the robotics and traditional intervention, the control group and experimental group were exposed to the same instrument in the form of a post-test. The test instrument was a ten-item multiple-choice assessment instrument with one right answer and three distracters per question. The test instrument also had four open-ended items embedded and some of the assessment questions derived from the National Curriculum.

1.8.1 Procedure

An activity manual with lesson plans covering the four different concepts of Newton's Second Law was used. For the intervention, 21 learners from a Technical Sciences class consisting of 42 learners were randomly selected and formed the experimental group with the researcher leading the activities using a LEGO Mindstorms kit. There are 828 mechanical parts in a LEGO Mindstorms kit which includes a microcomputer "brick" with three input and output ports. The mechanical parts consist of gears, axles, connectors, motors, sensors and LEGO bricks. The programming language used is called EV3 which has a graphic user interface of a block/visual Java programming.

The researcher introduced to robotics to the learners by engaging in a building and programming introductory exercise of a "Riley Rover" robot using the Mindstorms EV3 software. The activities advanced over time addressing different concepts of Newton's Second Law of motion such as the force of friction, tension force, acceleration, velocity and net force. After three weeks, a post-test was administered to both the control group and the experimental group to see whether there was a significant difference in the achievement scores regarding the topic of Newton's laws of motion.

1.8.2 Robotics intervention curriculum and activities

The intervention involved Newton's Second Law concepts with a robotics component embedded in each activity. The following section outlines the curriculum sequencing and progression of the robotics intervention activities:

1.8.2.1 Pre-Activity: Introduction to robotics and programming

The learners were introduced to components of the Mindstorms EV3 Kit, the programming interface as well as the basic programming language. They built a Basic Riley Rover as seen in Figure 1.1.

Figure 1.1: Basic Riley Rover

During the first two days, the learners were inducted to be able to use the action blocks of the EV3 programming software to teach the robot to perform the following tasks: Move forward/backwards, move slowly/fast, turn left/right, move in a square.

1.8.2.2 Activity 1: Newton's second law of motion equation – Mass, acceleration and net force

In this activity, learners had to connect two blocks with a light inextensible string and connect the system to the robot that they had built with a light inextensible string. The robot then had to be programmed to move at constant power (as power is used in the EV3 programming language), and record the time it takes for the robot to pull the two wooden blocks across a specific distance. Learners had to calculate the acceleration using a given formula, and the force applied on the system using Newton's second law equation.

1.8.2.3 Activity 2: Force of gravity and normal force

In this activity, the learners were required to build and program a robot with the ability to move a two-block system – Both on an inclined plane. The learners had to include power attachments and use other equipment such as a protractor to measure the inclined angle. The robot had to be programmed to move a certain distance and learners recorded the time and calculated the net force acting on the system.

1.8.2.4 Activity 3: Frictional Force

The learners were required to connect two blocks with a light inextensible string and connect the system to the robot with a light inextensible string. The learners then had to program the robot and record the time it takes for the robot to pull the two wooden blocks across a rough surface, and hence, use Newton's second law of motion to determine the kinetic friction in terms of μ_k. The open-ended question in the activity required learners to think and construct their understanding of whether the surface area of the block or the type of surface affects friction.

1.8.2.5 Activity 4: The Force of Tension

In the last activity, learners were required to build and program a robot with the ability to move a two-block system – both hanging vertically on a frictionless pulley. The learners were required to program the robot to move at constant power and distance, and then record the time. The learners were then tasked to calculate the acceleration of the system using a given formula. The activity further required learners to reflect on how they arrived at their solution, which is how the researcher intended to initiate a conceptual change in the learners.

1.8.3 Sampling

The population group consisted of Technical Sciences learners, where random sampling using MS Excel was applied. The sample was evenly spread across the entire reference population, which was the Grade 12 Technical Sciences class. The Grade 12 Technical Sciences learners were 42 in total, and all 42 learners agreed to participate in the study. Thus, the researcher divided the class in two, to have one experimental group, who participated in the intervention, and one control group, who continued with the traditional intervention offered by the Technical Sciences teacher.

1.8.4 Data collection

A pre-test and post-test were the primary methods of data collection. Qualitative questions were embedded in the pre-test and post-test instrument that required learners to answer fully.

1.9 DATA ANALYSIS

Inductive and deductive techniques were used to enable the researcher to analyse the findings to best address the aims of the study and make recommendations to respond to the questions informing the research study. Descriptive statistical analysis was used to analyse the pre-test results, the post-test results and the comparison between the two sets of data. The quantitative data were analysed using the Statistical Package for the Social Science (SPSS) on a Windows® platform. An independent t-test was conducted on the pre-test and post-test to compare the mean scores of the control group and the experimental group. The researcher analysed the frequency distribution, mean, median, mode, range and standard deviation of the two data sets to answer the quantitative questions.

In the second stage of analysis, the researcher engaged with the qualitative data deductively, approaching the data from a more general to particular understandings of the participants. The researcher began first by unpacking the qualitative pre-test results and identifying whether any responses were revealing sound conceptual understanding for each theme, namely acceleration, net force, frictional force, forces on an incline and tension force. The researcher then analysed the responses revealing any misconceptions. The procedure was repeated for the results of the test after the intervention. The pre-test and post-test responses were then compared in the third phase of the process. The last phase of data analysis included analysing responses for each participant in instances where a participant gave the correct response in the multiple-choice test, but a wrong explanation or wrong answer in the open-ended questions.

1.10 ETHICAL CONSIDERATIONS

Privacy - Children constitute a vulnerable group in society and hence their privacy needs to be respected. The results from the study were both of a quantitative and qualitative nature, however, the names of the learners are not revealed in the dissertation or appendices and their anonymity has been respected.

Transparency - During the weeks of the study, the data collection and pre-analysis stage, the researcher was transparent with learners and parents about the curriculum and the process, including what was being collected and how it would be used.

Responsibility - Participation in the study was voluntary, and none of the participants was made to feel uncomfortable or violated during the study. The researcher took responsibility to make sure that learners' rights were not infringed upon, and that they felt safe during the entire process.

Consent – permission was sought from the learners, parents, school governing body, DBE as well as the ethics committee at the University of Pretoria in written form.

Communication – representatives at the University of Pretoria, and other stakeholders such as the school governing body and DBE will receive the findings and significance of this study which will be communicated in a clear, straightforward manner using appropriate language.

1.11 STRUCTURE OF THIS DISSERTATION

This dissertation comprises of six chapters, concomitant of this first chapter, which is the introduction and motivation as to why the researcher intended to do the study. In the second chapter of this dissertation, the conceptual framework is unpacked and the aim of the study is supported by a review of the literature that guided the study. The conceptual framework, which informed the study is discussed as a combination of the theories of constructivism, constructionism and the conceptual refinement instructional approach (CRIA).

In the third chapter, the research methodology is explained in terms of the research design, paradigmatic assumptions, data collection methods and an overview of the processes that were undertaken. The justification of the methods used and data collection are explained further in detail.

In the fourth chapter, the result of the research from the collected quantitative data is thoroughly analysed. The researcher collected data before and after the intervention. The results were discussed according to the relevant statistical parameters, which described the general features of the distribution of the data from the pre-test and the post-test. The fifth chapter consists of qualitative data analysis. The researcher discusses the qualitative results of the study, which are the responses from open-ended questions that required participants to describe their understanding of acceleration, net force, frictional force, gravitational force and the force of tension.

The last chapter outlines what was discovered during the research. The researcher will discuss the implications of the results of this study against existing literature, and the research questions that guided the study.

2 CHAPTER TWO: LITERATURE REVIEW

2.1 INTRODUCTION

In science education, teachers are always looking for different approaches to capture learners' interest to introduce or re-enforce concepts. One approach that could be implemented is educational robotics. In this chapter, an analysis of the literature regarding the current research undertaken on robotics in education and the learning theories that have supported technology implementation in schools will be presented. The first section will provide a background on the impact technology has had on education, followed by a discussion of the fourth industrial revolution and its consequences regarding the recipient learner and the South African education system's current state. Teachers' impact on learners cannot be ignored as they constitute an important aspect in facilitating learning. Henceforth, the subsection that follows discusses teachers' perceptions concerning technology in education and the willingness or lack thereof regarding integrating technology in their pedagogy and teaching approach.

It is important to discuss what robotics education is in terms of the background, and the theories underpinning the approach. The researcher will present a review of the literature on aspects of innovative constructivist pedagogical approaches to robotics education and a discussion of how robotics can be used in conjunction with or to support other subjects. The contribution of robotics to authentic learning will be discussed, looking at research that has already been conducted in the educational space. Inherent to this study is Technical Sciences as a subject; thus, the curriculum's objectives, intended curriculum aims, and the assessed curriculum are explored. Underpinning this research was the notion of an intervention strategy; therefore an examination of the skills development and collaboration output from intervention strategies in other studies are presented. A discussion on how robotics was used as an intervention strategy in Technical Sciences will be addressed. Finally, a conceptual framework is presented, taking into account approaches to learning Technical Sciences in the form of the Conceptual Refinement Instructional Approach (CRIA), as well constructionist and constructivist approaches to robotics in education.

2.2 TECHNOLOGY IN EDUCATION AND THE ENVISAGED LEARNER OF THE 21ST CENTURY

There is an anticipation of the 21^{st}-century learner who will participate in an industry driven by automated jobs in the next 20 years, with the driving force for this major global job creation being robotics (Sergeyev, et al., 2018). Furthermore, such anticipation is observed through Eguchi's (2014) research who accentuates the accelerating advancements in technology powered by the rapidly changing world. There is a so-called “flattening” of the world driven by the internet and social media platforms and technological tools in shorter timeframes (Eguchi, 2014). The researcher posits that as one way to prepare learners for such a future, educational robotics should be integrated into the school curriculum. Such a move could harness learners' ability to become future creators instead of passive consumers of technological products (Eguchi, 2014). Afari and Khine (2017) further emphasise how learners need problem-solving, critical thinking and collaborative skills to be acquired through technology. Technology in education provides authentic activities that allow learners to actively solve real-life problems so that there is a transfer of learning beyond the classroom. Social skills are required through peer collaboration and group learning, while critical thinking skills are crucial to exploiting possibilities and opportunities in the next five years. Therefore, robotics must be introduced in education to achieve the skills mentioned above (Afari & Khine, 2017). Through authentic learning exercises, learners should be assisted in making connections between technological and content knowledge. There are currently insufficient platforms that provide this kind of opportunity in the CAPS curriculum and the South African Education system (Banas & York, 2014).

2.2.1 The 4th Industrial revolution and the South African education sector

On the 8th March 2019, the Minister of Basic Education of South Africa announced in a media briefing that to gear up for the fourth industrial revolution, the DBE will introduce a robotics curriculum from Grade R to 9, which will be a pilot implementation in 2020 for 1000 schools in five provinces. The DBE announced in July 2020 that they are finalising the coding and robotics curriculum that would first need to be quality assured before it is piloted at schools, (South Africa Government News Agency, 2020).

The term 4th industrial revolution has been in the minds and conversations of most academic exchanges, albeit termed 4IR or “Industry 4.0” (Karabegović & Husak, 2018). In their research, Karabegović and Husak (2018) explain that as one of the most technologically advanced countries globally, the terminology of the fourth industrial revolution first appeared in Germany in 2011 as “Industry 4.0”, which depends on new and innovative technological achievements. Fourth technological revolution describes the automation of processes in production, intelligent robots, advanced sensors, network communication and innovative technologies amongst many others, (Karabegović & Husak, 2018). As a researcher, this raises questions about what implications this industry will have for the South African education system in terms of curriculum preparedness.

Chetty (2015) proposes that learners need to be challenged to think in new ways. Likewise, there is a need for innovative methods to support learning in today's rapidly changing world. The transformation of education to equip learners with 21stcentury skills by introducing robotics was studied by Barak (2009) and Varney et al. (2012, as cited in Toh et al., 2016), and it was found that high school learners produced innovative solutions to project-based problems as a benefit. A study by Luckin et al. Forcier (2016) proposed that the cognitive demand of future jobs is much greater than the jobs currently available and learners need to achieve higher-order skills such as problem-solving. Essentially, they will need to learn efficiently and build collaboratively on others' ideas.

2.2.2 Perceptions of teachers who integrate technology in the classroom

Teachers are facilitators of learning in the learning environment. The learning environment includes the physical environment (contextual factors), the teacher, the learner, and the Learning Teaching and Support Material (LTSM). Thus, understanding the perceptions of teachers with regards to technology in education is an important aspect. The availability of technology in schools does not guarantee pedagogical integration or usage, which Bana and York (2014) report may not come to pass due to insufficient professional preparation.

In a study that assessed pre-service teachers' motivation to integrate technology, the intention was established as a reliable predictor of future behaviour. Teachers need to be intrinsically motivated to integrate technology in the classroom (Banas & York, 2014). In a systemic review carried out on the use of robots in education, Toh et al. (2016) examined different reports from researchers, which revealed parents, teachers, and learners' perceptions in integrating robotics in education. One study revealed that 86% of their learners would consider the path of engineering as a study field and showed some required competence level.

Professional teacher preparation programs should benefit from the knowledge of factors predicting teachers' intentions for technology integration. Teachers need to be encouraged to view robotics as a tool that can be both a pedagogical instrument and conjointly, a content area that can be used to improve learning (Banas & York, 2014). A study by Luckin et al. (2016) emphasises that teachers–alongside learners and parents–should be central to the design of technological tools. The methodology and environment in which tools are used should be considered to deliver the support educators need.

Toh et al. (2016) reported that the perceptions of different stakeholders such as learners, parents and teachers regarding robots, influence the chances of success of robotics programmes. Both parents and teachers need to be supportive and on board to increase the chances of success. Educational robots could be confined only to applications inside the classroom, where there is a lack of parental support. Furthermore, Luckin et al. (2016) reported an increase in technological literacy, new design skills and a greater understanding of the application of technology and artificial intelligence in education by teachers who participate in technology integration processes.

2.3 ROBOTICS EDUCATION

Many recent studies have used the words “education” and “robotics” together, to coin terms such as “Robotics Education” or “Educational Robotics”, (Angel-Fernandez & Vincze, 2018). However, the ideas and methodologies of robotics education originated in the 1960s, and after the 1990s, the research platform was extended to include many solutions available in schools. Angel-Fernandez and Vincze (2018), as well as Karim et al. (2015), imply that there is no clear definition of educational robotics and any statements ambiguously trying to define it may be elusive. This suggests that anyone may claim the term as long as robots are used in what they do. Henceforth in their study, Angel-Fernandez and Vincze (2018) define educational robotics as a field of study that uses robots in their pedagogy and approach to decision making. The purpose of introducing robotics is to improve teaching and learning by creatively using educational activities, tools and technology. Lego robotics can impact science and technology education throughout all levels from early childhood to graduate studies (Afari & Khine, 2017). Robotics may be used as a pedagogical tool, an approach to focus on specific topics or to support other subjects (Karim et al., 2015), and as a learning aid through social, collaborative learning activities (Angel-Fernandez & Vincze, 2018). Furthermore, Altin and Pedaste (2013) posit that curriculum inclusion of robotics should be both a learning object and incorporation in learning other subjects.

2.3.1 Theories underpinning robotics education

The relationship between constructivism and constructionism in the learning process is prominent in most educational robotics studies (Altin & Pedaste, 2013; Karim et al., 2015; Tocháčeka et al., 2016). There is an emphasis that through constructivism, learners are actively and continuously constructing their skills and knowledge through participation and involvement (Altin & Pedaste, 2013; Karim et al., 2015). The theory of constructionism further develops learners' knowledge by sequentially participating in practical activities where they create attractive and realistic products. Research by Karim et al. (2015) included pedagogical theories of learning robotics in line with constructionism and social constructivism theories, learning by design and active learning principles. Studies from Altin and Pedaste (2013) include the theory of situated cognition, which states the inseparability of doing and knowing, pivotal in robotics education. There is an emphasis on the learning situation and context of the individual participating and ultimately being absorbed in the social activity. Since the participant is allowed to build and program a variety of robots using Lego Mindstorms parts, Piaget and Vygotsky's principles seem to be highlighted through the notion of the learner being the constructor of knowledge (Afari & Khine, 2017). The learner manipulates artefacts through the building of physical objects and essentially enhances knowledge acquisition. There is no transmissive approach as the teacher is a leader and facilitator of learning instead of transmitting the information.

2.3.2 Pedagogy for teaching and learning in robotics education

Chetty (2015) defines how teaching and learning with the intention to facilitate intended learning outcomes as pedagogical approaches. In their review of educational robotics studies, Karim et al. (2015) concluded that the methodology used predominantly as a pedagogical approach in robotics education is inquiry teaching. This pedagogical approach was described as providing a platform for learners to practice their reasoning and questioning skills, reflection, decision making and communication. Tocháčeka et al. (2016) posit that collaborative learning takes place as learners are participants in their learning and partake in the knowledge building process. Furthermore, teachers are facilitators or advisors and organise learning activities. The most prevalent educational techniques, according to Altin and Pedaste (2013), are problem-based learning, constructionist, and competition-based methods. The most successful way for merging scientific and math topics with robotics was the competition-based technique, which employs competitions to achieve learning goals. However, the competition-based methodology's limitation is a lack of funding, since organising and participating in the competitions was financially limiting.

According to Altin and Pedaste (2013), discovery learning is an exploration approach to learning, which is more time-consuming. Teachers do not give guidance; rather, learners are left to their own devices in their quest to figure out how “things work.” Teachers guide students toward their responses rather than providing direct answers to questions. In collaborative learning, learners can interact during the learning process and create robotics education projects using problem-solving theory, (Altin & Pedaste, 2013). The aim is to improve strategic and dynamic skills in groups of two to four learners, as well as distributed collaboration between learners who share the same goal of task completion. Distributed cooperation, according to the methodology of collaborative learning, entails subtasks with a common objective that are first distributed among various group members, (Chetty, 2015). Teachers promote interactions, and most groups have two members, one of whom is in charge of hardware and the other of software, as agreed. In essence, it is a community of teachers and students who share knowledge, skills, and strategies to improve educational robotics by sharing knowledge, skills, and strategies between groups.

The problem-solving approach aims to improve knowledge and skills, as well as the design of algorithms, (Altin & Pedaste, 2013). When faced with a problem, students prefer to concentrate on how to utilize the programming language rather than the problem itself. Therefore, in the problem-solving approach, learners use debugging to try to understand the reasoning behind their programming code when robots first do what is ordered, rather than what is planned. Constructionism and the physical reflection of software in the actual world, according to Atlin and Pedaste (2013), are the roots of this.

Learners plan for competitions by building hardware and software in competition-based learning (CBL). As a result of the problems that students will encounter, this method will require debugging. When attempting to answer the challenge, students must apply knowledge from topics such as mathematics, physics, programming, and science. Learning by competition has proven to be the most successful method of gaining knowledge in STEM subjects, (Altin & Pedaste, 2013). Camilleri (2017) and Chetty (2015) advocate for the use of Project-Based Learning (PBL) when integrating robotics in school subjects. In PBL, tasks are assigned to a group of learners and may need collaborative research or be concentrated on problem-solving solutions. PBL is also a constructivist learning theory implementation. which is one of the theories that underpin this study. Altin and Pedaste (2013) posit that inquiry learning, which can be traced back to discovery learning, is a constructivist approach to learning and exploring by experiments or observation that is highly self-directed. Inquiry learning, like the other techniques covered in this section, may be viewed as a roof technique that protects a variety of different educational robotics techniques.

2.3.3 Robotics supporting Technical Sciences

Robotics has special characteristics: It is essentially multidisciplinary, allowing collaboration and immersion into diverse themes when designing a learning activity. Different stakeholders can be involved in classroom and extra-curricular learning settings, which promote creativity and the introduction of innovations in organisations and schools. In the systemic review carried out on the use of robots in education, Toh et al. (2016) examined studies published within the last decade to determine the effectiveness of using robots in education. Researchers validated their use of robots in non-experimental and quasi-experimental approaches; the studies found some degree of developmental influence on the children’s cognitive, conceptual, language and social skills.

Afari and Khine (2017) and Karim et al. (2015) discussed the role of robots in teaching subjects such as mathematics, physics, music and languages. Existing literature (Karim et al., 2015) highlights robots' social use to help develop children's cognition and intellect. Moreover, in physics, certain concepts and skills were reported to be supported by robot-based activities. The learners demonstrated creative thinking and practical understanding from learning of the concepts according to studies by Alimisis (2012) and (Yanik et al., 2016). The topics that showed an improvement in understanding of the concepts were kinematics, Newton's Law's of motion, ratios, and interpretation of graphs. The LEGO Mindstorms robot has been used in studies (Alimisis, 2012; Karim et al., 2015; Yanik et al., 2016) to collaboratively learn the relationship between the variables of time, distance and velocity in kinematics. The tangible aspect of robotics enabled learners to actively manipulate variables such as forces, friction, weight, ramp incline, and the radius of the wheel, which inertly targets Newton's laws of motion in such kinetics-related activities (Karim et al., 2015). Concepts of energy and energy conversion are addressed through construction activities that include, for example, rubber bands, while ratio concepts are assimilated through the different sizes of the gears, cogs and pulleys that can be practically used to explain the theoretical models of gear ratios. One outstanding research finding was that the learners' ability to explain science in written form has improved, as well as their ability to construct and interpret graphs (Karim et al., 2015).

In light of the mandate from the government for inclusivity in the South African education system, especially for previously disadvantaged learners, innovative pedagogical approaches need to be considered and effected to favour the development of abstract reasoning, which can be done through Lego Mindstorms (Chetty, 2015). The traditional teacher-centred approach, which consists of lecturing, questioning and demonstrations, where the teacher is the expert who transfers knowledge, is still the most prevalent in South Africa (Chetty, 2015). Social constructivism, collaborative learning, peer-lead learning and problem-based learning are a few philosophies that Chetty (2015) describes as being learner-centred pedagogical approaches. Merden et al. (2017) conclude that the tangible aspect of robotics education allows learners to explore the features of the physical and mechanical materials and programming more easily. Through robotics, teachers could combine technology and engineering topics to make science and mathematics concepts appear more concrete in real-world applications (Merdan et al., 2017).

2.4 TECHNICAL SCIENCES CURRICULUM

2.4.1 Intended curriculum

The Curriculum and Assessment Policy Statement (CAPS) for Technical Sciences

(Grade 10–12), describes Technical Sciences as a subject which is used to enable and support the technical disciplines of mechanical technology, electrical technology and civil technology. The subject is intended to promote an increased understanding of the scientific principles which underpin all technological disciplines. In terms of articulation, learners who take Technical Sciences should have improved access to applied technology courses, vocational career paths and entrepreneurial opportunities, to enhance the economic growth and social well-being of an increased number of citizens in South Africa (Department of Basic Education South Africa, 2016). The CAPS Technical Sciences document further emphasises the promotion of critical and logical thinking skills, sequential reasoning processes and the ability to integrate scientific knowledge in a more informed way in their subject offerings in technology. The practical component of the subject encompasses investigative aspects to develop planning skills, observing, measuring, making conclusions and acknowledging limitations. The curriculum includes mainly physics, with some chemistry topics. The rigid design of the curriculum ensures that teachers know what content should be taught in a specific time-frame. The CAPS document supports teachers who need guidance on the sequencing and planning of the delivery of the curriculum, however, this approach may be limiting for innovative teachers.

2.4.2 Assessed curriculum

Assessment is defined as a continuous process that is planned and undertaken to identify, collect and understand data about learner performance. In Technical Sciences, informal assessment tasks are used for daily monitoring of learners' progress and include daily activities such as homework, classroom activities, practical work, discussions, and observations. Practical Assessment Tasks (PAT), including experiments, are used for the assessment of practical, reporting and investigative skills. The PAT consists of two experiments and one project. Assessment for promotion purposes comprises 25% School-Based Assessment (SBA), 25% Practical Assessment Task (PAT) and 50% written examinations. The project could be the construction of a device such as a motor or building a physical model or a practical investigation. Control tests and examinations assess the content and application of knowledge. The Technical Sciences CAPS states that control tests should be written under controlled conditions within a specified period and should assess performance at different cognitive levels. The end-of-year examinations consist of two question papers that are externally set and moderated.

2.5 THE EFFECT OF INTERVENTION STRATEGIES

In their study aimed at investigating strategies to improve academic performance, Garcia and Al-Safadi (2014) found that intervention strategies utilising formal and informal assessment were of assistance in the upliftment of the standard of education in computing and information technology programs. Intervention strategies in education are defined by Garcia and Al-Safadi (2014) as the systematic directives in programmes where there is a need to promote progress and improve learners' academic performance. The objectives of academic performance are specific and measurable, thus, all factors on the improvement of learner performance should be identified, and progress should be monitored if necessary (Garcia & Al-Safadi, 2014). Intervention strategies are employed when a teacher or instructor sees a gap in learners' ability to help boost learners' performance and expand their knowledge. Examples of intervention strategies explained by Garcia and Al-Safadi (2014) include tutoring, student support programs, behaviour support programs, life skills programs, external support programs, parental involvement, instructor's capacity building, integration of warm-up activities, using small groups and emphasising real-life applications.

Learning activities during interventions should progress from simple level thinking to complex thinking, and there are different tools to support the methodology. When reviewing studies that investigated achievement scores, scientific concepts and sequencing skills, instruction of STEM concepts in the science curriculum using robotics was found to be effective for 9– 11-year-olds (Barker & Ansorge, 2007). Furthermore, Kazakoff et al. (2013) supported intensive tangible robotic curriculum programs to increase sequencing skills, which is one of the many skills contributing to comprehension ability of kindergarten (pre-school) learners.

2.5.1 Skills development

Toh et al. (2016) reviewed research done on robotics in education, and the studies revealed that in some cases there was an increase in mean scores from pre-test to post-test, therefore in those cases one can conclude robotics was effective in re-enforcing STEM concepts. Although Williams et al. (2007) reported a significant difference in physics knowledge acquisition, but not for scientific inquiry skills. A study by Slangen et al. (2011) reported that robotics helped challenge pupils to manipulate, reason, predict, hypothesize, analyse and test. Furthermore, the review by Toh et al. (2016) also indicated that some of the skills displayed by learning with robots included an increase in conceptual understanding, demonstrations of perseverance, motivation and responsiveness. Also, teachers reported that robot-based activities seemed to improve the level of engagement, attitude and motivation in their learners, (Karim et al., 2015).

2.5.2 Collaboration

Collaboration in small groups has proven effective as an intervention strategy, especially for learners who do not perform well. The effectiveness of collaborative learning is supported by researchers Luckin et al. (2016) and Garcia and Al-Safadi (2014) as being able to encourage articulation, reflection, constructive dialogue as well as shared knowledge. Participating in small groups affords most learners with different learning styles to interact with their peers, ask questions freely and benefit from peer explanations, (Garcia & Al-Safadi, 2014). The collaborative aspect of Lego Mindstorms, where learners can conduct projects in their small groups, was viewed as an effective instrument for improving team skills by Varney et al. (as cited in Toh et al., 2016). Although collaboration between learners may not be spontaneous, Luckin et al. (2016) imply that robotics can provide intelligent support for collaborative learning and also enhance motivation. Furthermore, Toh et al. (2016) highlighted the promotion of problem-solving skills and collaboration by elementary school learners who were involved in the construction and assembly of their robotic objects. Learners were provided with the opportunity to be deeply engaged in the thinking process of their problem solving and collaborative efforts which enhanced their learning experience with their peers.

When considering 21st-century skills and prospects, there is a need for learners to be effective in collaborative problem solving and innovative approaches to problems, they need to be able to build on others' ideas and sensitively critique an argument (Luckin et al., 2016). The underlying learning theory of constructivism is undertaken through various activities using Lego Mindstorms. This is evident in the collaborative effort of peer work through knowledge combination, problem solving and discussions in the construction of their robots. Luckin et al. (2016) suggested that collaboration can nurture higher learning results than individual learning.

2.5.3 Differentiated learning

Scaffolding is defined by Luckin et al. (2016) as a teaching approach of gradually scaling back assistance to a learner to enable problem-solving abilities, task implementation or goal achievement. In robotics. Learning is scaffolded while programming skills are developed, and programming concepts are reinforced while practised in a fun approach (Chetty, 2015). Artificial Intelligence (AI) in education can also inform approaches to learning that do not involve technology, such as enabling classroom teachers to see and understand the micro-steps that learners go through in learning physics, or the common misconceptions that arise (Luckin et al, 2016).

Verma (2018) supports the premise that AI could change the role of teachers as facilitators and encourage the constructivist view of learning, where learners create their learning and the teacher scaffolds this learning process by providing guidance and support.

A common problem that teachers experience is how to differentiate instruction and have learners of multiple intelligences and capabilities in the same setting. Robotics may assist in differentiated learning as teachers fail to meet the needs of all learners since not all learners are achieving their potential at school, (Forcier, 2016; Luckin et al., 2016). Robots have the ability and potential of capturing and retaining learner attention, and thus allows the teacher to allocate different tasks at different paces for different learners at the same time (Luckin et al., 2016). Chetty (2015) further elaborates that in a language dependant environment, different learning styles can be accommodated and skills developed since the approach is action-orientated and does not rely on teacher explanations.

2.5.4 Real-world application using robotics

Technical Sciences as a subject is meant to allow learners to integrate everyday knowledge to what is learnt in the classroom. There are solicitations to reference some scientific concepts, and teachers are asked to identify appliances or objects which are in common daily use in homes, however, there are missed opportunities as most concepts are discussed in the abstract as this study will later reveal. Abstract concepts are challenging to understand as they cannot be related to real-world situations, and this is further aggravated by traditional pedagogical approaches, hence Chetty (2015) proposed introducing Lego Mindstorms to provide the distinctive prospect of changing the classroom environment. Furthermore, learners are allowed to tackle real-world situations using the Lego Mindstorms robot. Concepts of programming are reinforced and to some degree, the level of motivation is increased during the experiment (Chetty, 2015). The insights of different stakeholders, the influence of robotics on behaviour and development, the type of research conducted, and the perceptions of children on robot design were examined in a systemic literature review by Toh et al. (2016). There were highly motivated responses from the learners, because of the interactive and engaging experiences created by the robots. Similar studies by Toh et al. (2016) revealed that a mixed-reality environment was provided by the use of robotics in a story-telling approach to education. The study found that the children reacted positively, they were involved, coordinated and engaged in what they should learn because the story-telling involved a robot that they created.

2.5.5 The contribution of robotics to authentic learning

An activity that contributes to authentic learning does not only depend on one criterion but several characteristics. Robotics has real-world significance, in light of the 4th Industrial revolution's expected skills needs, and it inexplicitly defines tasks that allow the learners to apply creative thinking and produce innovative solutions (Banas & York, 2014). Furthermore, a case study by Chetty (2015) also revealed that the Lego Mindstorms platform allowed learners to engage in real-world problems shifting from traditional learning. An experience that is engaging and interactive underpins most robotics in education studies such as the studies reported by Toh et al. (2016) point out. The application of robotics in education is proposed by Timms (2016) as a way of shifting the traditional limitations of the technology paradigm and teaching pedagogy, to providing more social interactions befitting to our biological predispositions in learning. Considerable advances in the field of robotics in education have been made as researchers explore socially assistive robots, robots in the classroom and the inevitability of robots being helpful in the education sector (Timms, 2016).

Another characteristic of robotics which contributes to authentic learning is that it provides an opportunity for the learners to collaborate, reflect and create their products (robots) which allow for a diversity of outcomes. Cheli et al. (2018) infer that creative learning skills are needed in educational robotics since the role of the teacher would be to mentor and to facilitate unpredictable problems stemming from the creativity of the curriculum. A study by Banas and York (2014) proposed that pre-service teachers' motivation to integrate technology could be improved by authentic learning exercises, as the contextual gap between pedagogy and technology needs to be bridged.

In his study to understand whether Lego Mindstorms can be used as an innovative pedagogical tool to learn computer programming, Chetty (2015) discovered that learners' problem-solving skills were developed and cerebration was encouraged. Understanding and motivation were identified as key elements for learning that were provided by Lego Mindstorms tasks. Several researchers (Afari & Khine, 2017; Alias & Ibrahim, 2016; Rand et al., 2018; Toh et al., 2016) also indicated that motivation and learning seemed to improve with the integration of technology in a classroom setting. This is applicable to this study, because Technical Sciences has a few abstract concepts that need an emphasis on their real-life application value, for learners to see the meaningfulness and use of the abstract concept. Garcia and Al-Safadi (2014) report that the real-life application of an intangible concept increases learners' interest in a course and makes the subject more significant.

2.6 CONCEPTUAL FRAMEWORK

Recent research in physics education has shown that learners cannot relate what they are taught in the classroom to what they experience in the real world (Soong & Mercer, 2011). Newton's second law of motion is a topic in the mechanics theme that is challenging, which can be attributed to the resistant misconceptions that arise within learners globally, (Hestenes et al., 1992). An approach of robotics as an intervention strategy in Technical Sciences is proposed, to possibly address learner misconceptions and propose a different learning and teaching pedagogy for Newton's second law of motion. In educational robotics, the frameworks of constructionism and constructivism are applied in research, whilst CRIA by Lemmer (2018) is used to understand the science of learning. Thus, considering the insufficient literature regarding Newton's second law of motion and robotics, a new conceptual framework against the background of constructivism, constructionism and the CRIA model of Lemmer (2018) was proposed.

2.6.1 Cognitive Refinement Instructional Approach (CRIA)

2.6.1.1 Conceptual refinement

Lemmer (2018) elaborates that a conceptual refinement model uses what learners perceive in their daily experiences, to form conceptual knowledge that is improved to formal physics knowledge. Cognitive refinement instruction begins with the discovery of a productive resource from daily practices that can be expanded into scientific ideas (Lemmer, 2018). A conceptual change approach is proposed to address students' misconceptions in constructivist physics education (Lemmer, 2018). Researchers Duit and Treagust (2003) coined what children intuitively know as "children's science" from how knowledge and understanding of what they experience are developed. Duit and Treagust (2003) believe that when students come into science instruction, there are already pre-existing deeply rooted ideas about science, which are misaligned to the correct scientific concepts. Thus, the notion of conceptual change was developed with the purpose of scaffolding students' pre-existing ideas towards the correct science concepts.

2.6.1.2 Conceptual change

Duit and Treagust (2003) suggest that conceptual change may occur at different levels, as there are different types of conceptual change: assimilation occurs through rearrangement of weak knowledge known as conceptual capture; while accommodation is radical knowledge restructuring known as a conceptual exchange. Conceptual change has been misunderstood as an interchange of science concepts to substitute pre-instructional concepts. It is emphasised that the learning domains consisting of pre-existing knowledge need to be reorganised to allow new acquisition of intended science concepts (Duit & Treagust, 2003). Conventional conceptual change is a top-down method that aims to substitute misconceptions with scientific accurate ideas, but that is not easy to achieve. Bottom-up approaches, such as conceptual refinement proposed by Lemmer (2008), aim to narrow the gap between students' instinctive notions and the scientific conceptions.

2.6.2 Application of principles

The fundamental principles of the CRIA will be incorporated in robotics activities in the following manner to guide learners to solve problems involving Newton's Second Law:

1. *Robotics activities connecting classroom activities to everyday experiences*
   Lego Mindstorms robotics kits serve as tools of abstract learning in science; they provide authentic learning where learners can use their physical senses to construct their learning from their experiences.
2. *Generalisation*
   During robotics activities, learners' attention is directed to observe general important features in new and existing information. Networks between prior and new information progressively form knowledge, and students should receive guidance on how to direct their attention to critical aspects of what should be known.
3. *Conceptual knowledge*
   Assimilations occur through inductive generalisations from experiences in different robotics activities. Conceptual learning develops through repeated experiences of critical features. There are an extensive refinement and rearrangement of existing cognitive schemas to guide understanding of physics concepts.
4. *Abstraction to Formal Knowledge*
   Open-ended questions prompt learners to reflect on their learning, be aware of misconceptions and be conscious of what they already know and their limitations. Conceptual structures are recalled and expanded to include formal physics. The difference between formal knowledge and conceptual knowledge is the awareness of learners being mindful of their learning and restrictions.

2.6.3 Constructivism

In most of the research conducted in educational robotics, constructivism is the underpinning theory whereby learners use their own experiences to construct knowledge through mediated interventions with objects or people (Cho et al., 2017). Piaget and Vygotsky's learning theories support the constructivist's view that through assimilation and accommodation, robotics tools are used as manipulatives to develop new knowledge (Cho et al., 2017). Constructivism has its roots on the premise that one may construct their knowledge and understanding through the reflection of experiences. Each individual can make sense of their own experiences through mental models or rules, and adjusting these models to accommodate new experiences constitute learning.

2.6.4 Constructionism

The study by Alias and Ibrahim (2016) also reported that traditional teaching and learning methods where learners are passive proved to be ineffective for learners to form the conceptual basis of physics principles. Learners only rely on textbooks and could not implicitly be involved in actively understanding the underlying concept of knowledge, but they must accept whatever the teacher conveys to them (Alias & Ibrahim, 2016).

In a constructionist environment, learners are empowered to learn in connected, meaningful approaches as they have the opportunity to build inventive objects that function by content that is meaningful to them in their context (Berland et al., 2014). Constructionism in educational robotics research has been used as a framework to comprehend how learners advance their skills and knowledge by using robotics technologies (Cho et al., 2017). There is a conscious engagement in constructing artefacts, which represents what the learner "thinks with". In this study, learners will be encouraged to become active participants in their learning and become researchers in activities based on Newton's second law, whereby guidance will be provided to scaffold physics concepts while they explore those concepts through meaningful play.

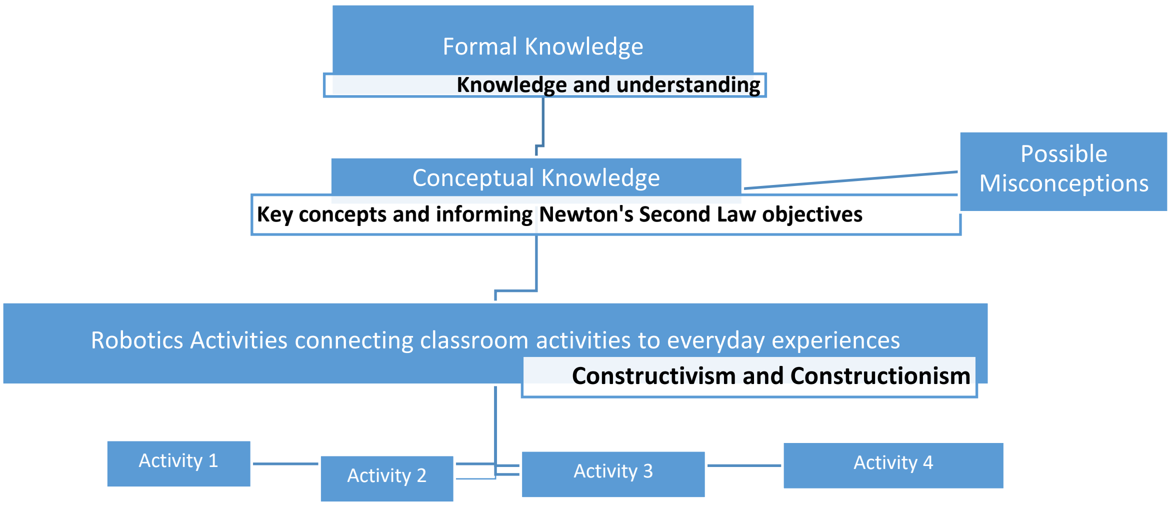


Figure 2.1: Illustration of the application of the conceptual framework using constructivism, constructionism and the CRIA

2.6.5 Implementation of the robotics intervention using the CRIA

The CRIA supports learning Newton's second law of motion from a cognitive perspective, taking social factors into account. Implementation of critical aspects of Newton's second law in various activities can be realised through a robotics intervention. The robotics intervention activities simulate real-life experiences; they use tangible resources to which the learners can relate. The learner's real-life experiences are refined through engagement and collaborative learning. The CRIA conceptual framework was incorporated with constructionism and constructivist principles whereby learners build artefacts for learning and use artefacts for learning. A bottom-up conceptual change approach is incorporated, whereby conceptual refinement takes place to narrow the gap between learner's intuitive ideas and scientific concepts. Conceptual resources – which are the intuitive knowledge and experiences that learners use to interact with the environment – are refined, and the tools that are applied to make sense of knowledge are developed.

1. Activities addressing critical aspects of Newton's second law and misconceptions– Table 2.1 below summarises the critical aspects of Newton's second law that need to be understood according to the CAPS policy documents and exam guidelines for Technical Sciences. The first aspect deals with the variables relating to Newton's second law equation, which is the relationship between the net force, mass and acceleration caused by the net force. The force of friction, tension and gravitational forces will also be examined.
2. Implementation of the conceptual refinement model–The robotics activities can be used to generalise and formalise intended conceptions to improve the test scores The CRIA model suggests implementing the selected activities in a specific order, in line with learner's experiences. The intervention activities start with the relationship between net force, mass and acceleration, which is the crux of Newton's second law equation. The activities move further to include added gravitational force and normal force including problems on an incline. Friction and tension are addressed last as they require more problem-solving skills and need learners to understand the basic idea of a net force, mass and acceleration. Lemmer (2018) posits that the variation of problems enhances learners' understanding of the validity of the relationship between net force and acceleration, although the context or situation may be different.

Table 2.1. outlines how the conceptual refinement model will be applied and indicates the test items in the pre-test and post-test instrument. The outcomes of the intervention will be measured with the test Items corresponding to the concept

Table 2.1: Application of the conceptual refinement model

INTERVENTION	CONCEPTUAL FRAMEWORK	TEST ITEMS
Activity 1 Newtons Second Law of Motion Equation – Mass, acceleration and Net Force	<u>*Constructivism (use of artefacts for learning)*</u> Learners will be facilitated through a robotics activity and encouraged to use the experience to create meaningful knowledge <u>*Constructionism (building of artefacts for learning)*</u> Build the Riley Rover Robot as indicated in the Lego Mindstorms instruction manual. Programming the Riley Robot to Move Straight Forward and Backward <u>*CRIA*</u> 1. Lego Mindstorms Robot - Practical activity of a robot moving across a distance 2. Attention directed to **constant speed, constant force.** 3. Physics principles to be articulated: **Net Force is associated with acceleration and not velocity.** Positive acceleration → increase in velocity in the positive direction or decrease in velocity in the negative direction. Negative acceleration → decrease in velocity in the positive direction or Increase in velocity in the negative direction. The net force is always in the direction of the acceleration 4. Open-ended questions to encourage reflection	N2M1 N2M2 N2M3 N2M4
Activity 2 Force of Gravity and Normal Force	<u>*Constructivism (use of artefacts for learning)*</u> Learners will be facilitated through a robotics activity and encouraged to use the experience to create meaningful knowledge	FG1 FG2

	Constructionism Build a robot either using the instruction manual or from their thinking Connect two blocks with a light inextensible string, and connect the system to the robot with a light inextensible string 1. Lego Mindstorms Robot - Practical activity of a robot pulling a two-body system on an incline 2. Attention directed to **Parallel and perpendicular components of Gravitational force**, 3. Physics principles to be articulated: Solving equations simultaneously to find external forces 4. Open-ended questions to encourage reflection: How does the angle of the applied force affect the acceleration of the system? How does it affect the gravitational force?	
Activity 3 Frictional Force	*Constructivism (use of artefacts for learning)* Learners will be facilitated through a robotics activity and encouraged to use the experience to create meaningful knowledge *Constructionism* Build and program a robot with the ability to move a two-block system - *CRIA* 1. Lego Mindstorms Robot - Practical activity of a robot pulling a two-block system 2. Attention directed to **Frictional Force, Normal force, Force Applied** 3. Physics principles to be articulated: Resolving a vector (force) into its components, Free body diagram, calculate the coefficient of kinetic friction. Frictional forces are sometimes useful as they may help objects move. Consider trying to walk if friction were not present; for example, the tread	FF1 FF2

	of a tire is designed to maximize friction (traction) between the tire and the road and friction can be used to produce heat when needed. 4. Open-ended questions to encourage reflection: Determine whether the surface area of the block or the type of surface affects friction	
Activity 4 The Force of Tension	<u>*Constructivism (use of artefacts for learning)*</u> Learners will be facilitated through a robotics activity and encouraged to use the experience to create meaningful knowledge <u>*Constructionism*</u> Build and program a robot with the ability to move a two-block system – Both hanging vertically on a frictionless pulley. <u>*CRIA*</u> 5. Lego Mindstorms Robot - Practical activity of a robot pulling two masses vertically, connected by a light inextensible string 6. Attention directed to **Tension** 7. Physics principles to be articulated: Gravitational acceleration is independent of weight. When the rope has mass, then one section of the rope will be pulling more mass (it will be pulling some rope and also the object) than the section farther from the object. So, close to the object, the rope pulls and exerts a force on only the object and a small amount of rope. At the end of the rope (the furthest point from the object) the rope is exerting force on both the mass of the object and all of the rope between the object and the end of the rope	FT1 FT2

	8. Open-ended questions to encourage reflection: What will happen to the Tension in the string(s) if you increase the power function when programming the robot? Does the way the masses hang matter, i.e. can a larger mass pull up on a smaller mass? Explain.	

Table 2.2: Conceptual problem-solving framework for robotics activities based on Newton's second law of motion

Knowledge and understanding		
Newton's second law of motion explains unbalanced forces. Unbalanced forces cause the acceleration of objects		
The acceleration depends inversely upon the mass of the object	$a = \frac{F_{net}}{m}$	The acceleration depends directly on the net force

Key concepts and informing Newtons Second Law objectives					
Acceleration	Mass	Net Force $F_{net} = m \cdot a$			
		Applied force $F_{applied}$	Force of Gravity $F_{gravity} = m \cdot g$	Friction $F_{friction} = \mu \cdot F_{normal}$	Tension $F_{Tension}$
Acceleration is the rate of change of velocity	Mass (property of an object) is a measure of the resistance to a change in velocity of an object	The force that is applied to an object or person	Weight is a force that depends on the local gravitational field	Friction forces oppose the motion (kinetic friction) or prevent the motion (static friction), parallel to the surface	Tension is the magnitude of the force exerted by a chain, rope or a string. The direction of that force depends upon the rest of the situation and the object that we are concentrating on at the moment.

Possible misconceptions emerging from literature (Hestenes et al., 1992)					
Acceleration	Mass	Net Force			
		Applied force	Force of Gravity	Friction	Tension
When two objects have the same speed, students think that they have the same acceleration at that time Some students believe that the speed of an object decreases even though the net force acting on the object is zero.	Heavier weight causes a greater acceleration in free fall	The applied force is necessary for the continuation of motion at a constant velocity although a frictionless medium is assumed Force dies out or increases to account for changes in an objects speed	Learners often think that Tension or the Normal Force equals to the weight of the object or body	Force dies out or increases to account for changes in an objects speed Applied force is necessary for the continuation of motion at a constant velocity although a frictionless medium is assumed	Learners believe the weight of the hanging mass equals to the Tension in the rope

Activity 1	**Activity 2**	**Activity 3**	**Activity 4**
A single object moving on a horizontal plane with friction **Constant velocity** means acceleration of the system is zero The system is in **equilibrium** Two-body system (joined by a light inextensible string): - Both on a flat horizontal plane with friction	Two-body system (joined by a light inextensible string): **Calculate normal force** when the applied force is at an angle Resolving **applied force at an angle** into components	Two-body systems (joined by a light inextensible string): - Both on an inclined plane with or without friction How to resolve different forces into the perpendicular and parallel components	Two-body systems (joined by a light inextensible string): - Both hanging vertically from a string over a frictionless pulley

2.7 SUMMARY OF THE LITERATURE REVIEW

This chapter has included a literature review of the theories applicable to this study.

Since there is a scarcity of research on the topic in South Africa, the majority of the literature reviewed is from international studies and research papers. The researcher discussed the perceptions of teachers who integrate technology in the classroom in light of the 4th Industrial revolution, to position technology in education and the envisioned learner of the 21st century.

The researcher discussed the theories underpinning robotics in education, the pedagogy for teaching and learning in robotics, and focused on the dearth of literature concerning the use of robotics in supporting Technical Sciences. The South African CAPS Technical Sciences intended and assessed curriculum was also discussed to give a background on the aims and exit level outcomes of the curriculum. Furthermore, the researcher reviewed literature on the effect of intervention strategies on skills development, collaboration differentiated learning.

The background and principles of the Cognitive Refinement Instructional Approach (CRIA), the theories of constructivism and constructionism were discussed in this chapter as the approach that underpins the conceptual structure of this study. The researcher discussed how the conceptual framework and underpinning theories were applied through the activities in the intervention and research instrument.

The next chapter discusses the methodology of this study, as informed by this literature review.

3 CHAPTER THREE: RESEARCH DESIGN AND METHODOLOGY

3.1 INTRODUCTION

In the previous chapter, the literature that supported and informed the study was reviewed. The conceptual framework, which guided the study, was discussed as a combination of the theories of constructivism, constructionism and the Conceptual Refinement Instructional Approach (CRIA). In this section, the research methodology is explained in terms of the research design, paradigmatic assumptions, data collection methods and an overview of the processes that were undertaken to analyse the data. The justification of the methods used and data collection are explained further in detail. Methodological decisions of this study are outlined in the figure below:

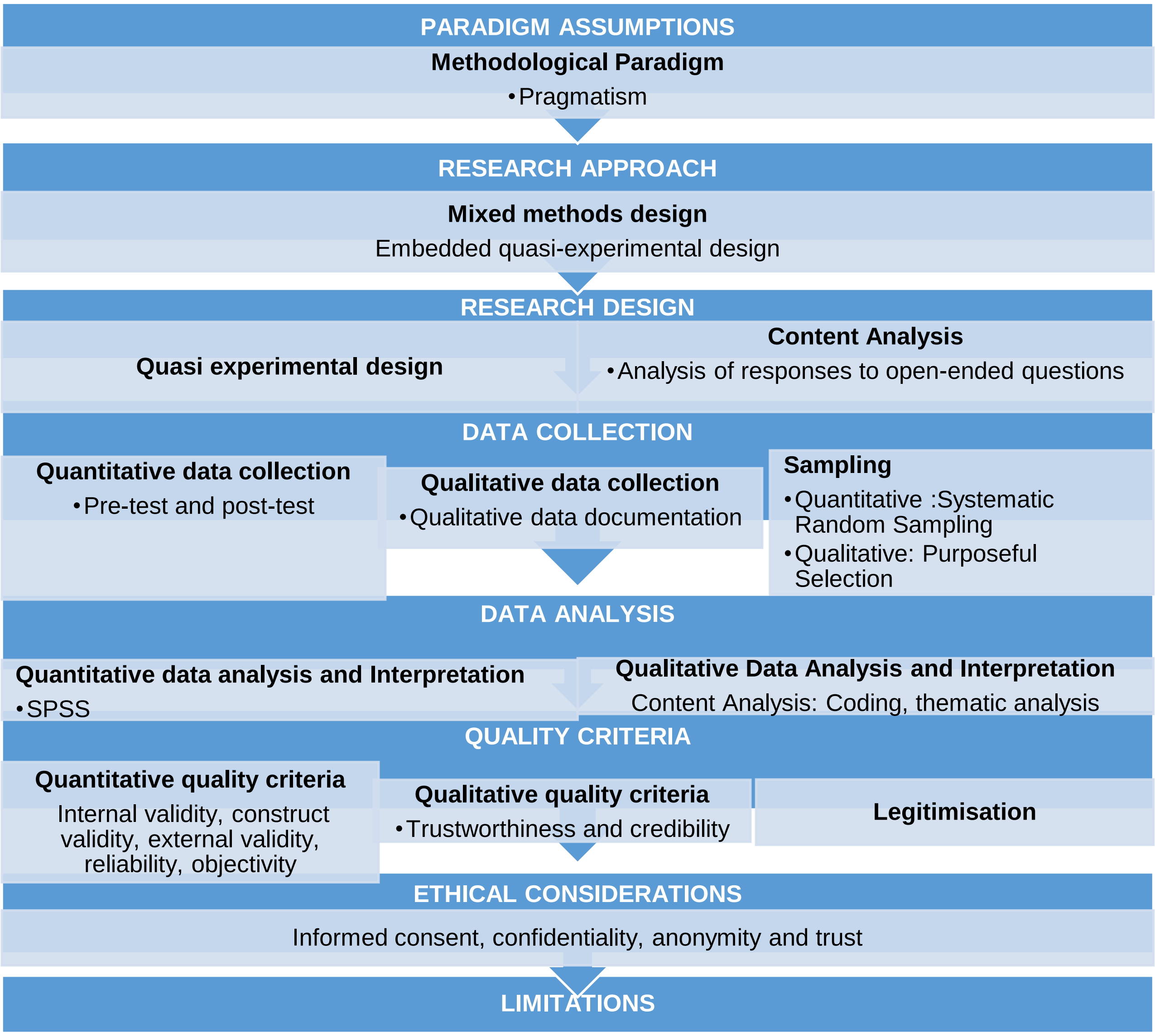


Figure 3.1: Decisions on methodology and outline of Chapter 3

3.2 PARADIGMATIC ASSUMPTIONS

As a science teacher for a few years, the researcher understood the pressures that are focused on matric results, underperforming subjects, achievement scores, and assessment being measured by a numerical outcome. However, although high marks give the learners access to university courses, the researcher was concerned that the high marks do not guarantee success in science-related university courses. Furthermore, with Technical Sciences only being first examined in 2018, the articulation of possibilities in Higher Education Institutions are still not clear. Therefore, the researcher sought to understand reality from multiple perspectives, namely of the post-positivist, who assumes the thinking that reality is a set of outcomes that can be measured and explained experimentally (Creswell, 2014); and that of the constructivist, where meaning is constructed by the researcher (Adeleye, 2017). The post-positivist tests hypotheses and measures reality's objectives through the scientific method's lens, where truth is absolute, and theory is tested. The researcher's objectivity is imperative for the data collection methods used, and the analysis of data. In this study, the researcher used a pre-test and a post-test to determine robotics' effect as an intervention strategy. In seeking to understand the meaning of the test results, the researcher included semi open-ended qualitative questions where the participants' responses could be analysed. The researcher hoped to make sense of the understanding that Technical Sciences learners have about Newton's second law of motion. Open-ended questions were used to understand learners' perspectives as they engaged with the robotics and their peers during the intervention. In line with the skills needed for the 21st century, skills such as team-work and communication were the focus of analysis. Since the researcher inherently adopted a way of thinking concerned with outcomes, while growing into a way of thinking that tries to understand meanings constructed from multiple perspectives, the philosophical assumptions thus suited a mixed-method approach. Therefore, in this section, the researcher presents the meta-theory that is the core of the paradigm, including the methodological paradigm, which encompasses the theories, methods, and details of the philosophical approach's frame of reference.

3.3 METHODOLOGICAL PARADIGM

The Technical Sciences CAPS was developed to produce learners who apply the knowledge learnt to solve real-world problems in the society they live in, (Department of Basic Education, 2014). The researcher understood that the intervention's instructional design should be led by the paradigm that focuses on real-world problems by whatever methods are most appropriate, hence the rationale of robotics as an intervention strategy was selected. Considering the statement above, the paradigmatic approach for this research study was from a pragmatist perspective.

3.3.1 The philosophy of pragmatism

The pragmatic worldview of thinking is pluralistic, and multiple perspectives of understanding truth and what constitutes reality is accepted (Adeleye, 2017). Creswell (2014) posits that a pragmatist does not commit to one philosophy and reality; instead, the researcher may employ mixed methods where they are free to postulate in the direction of either quantitative or qualitative assumptions. The pragmatist is more concerned with what method works best to solve the problem and, therefore, may use various techniques and procedures to meet the researcher's needs and purposes (Creswell, 2014). In collecting and analysing data, a pragmatist is not bound to only one approach. Investigators and researchers may use a combination of mixed strategies to provide answers in the best manner. The most suitable method for understanding what works will be used because it addresses the research problem. The pragmatist views phenomena based on intended consequences and the significance of the problem being addressed (Adeleye, 2017). Although it may seem that pragmatists haphazardly go in whichever direction they can, they are bound by the need to establish a purpose for the mixed methods employed, as well as a rationale for why the qualitative and quantitative methods need to be mixed (Creswell, 2014).

3.3.2 How pragmatism informed the approach to research

In its design, pragmatism is heterogeneous, taking into consideration the methods of data collection and analysis. Technical Sciences was first assessed in 2018 on NQF level 4, and only statistical data has been available in terms of the pass rate, average performance of learners in the subject, and the SBA marks. The researcher anticipated that more in-depth investigations were needed to comprehend why learners perform in the way they do, specifically considering the learner's aim and intentions by offering Technical Sciences as a subject. Thus, qualitative data-rich information of the learners' views and responses is imperative to understand "what works" in a Technical Sciences classroom. This mixing of qualitative and quantitative data is appropriate for the pragmatist to respond effectively to a research enquiry or problem (Creswell, 2014). As a physical sciences teacher, the researcher was aware that learners hold certain pre-conceptions upon entering the classroom, which may either be a barrier or assist in learning new concepts. The researcher accepted Creswell's position that the external world, which is the environment and contextual factors, independently builds the pre-conceptions that are lodged in the learner's mind.

The researcher wanted to understand how learners think, to improve the approach to the teaching method. It was, therefore, acknowledged that the traditional approach to teaching could not address learner's preconceptions and misconceptions. Still, once the researcher solicits perceptions from the learner, it might inform which approach would best teach Technical Sciences. The researcher believed that everyone had views and opinions of what constitutes truth; however, the researcher also believed that these truths should be tested and proved to be workable. The researcher aimed to understand how learners think, their line of thought, and determine the effectiveness of robotics as an intervention strategy in Technical Sciences.

3.3.3 Ontology

The ontology of pragmatism is varied, in a sense that multiple truths influence the decisions of the research. The ontological assumption of the reality in which the researcher understands the world is pluralistic – the reality is formed from multiple truths. The idealistic truth of the qualitative approach meets the materialistic truth of the quantitative data in the middle. Reality can be observed from multiple perspectives that are regarded for both the depth and the breadth of the various views of reality (Stuart et al., 2017).

3.3.4 Epistemology

According to a pragmatist epistemology, knowing is the result of experience based on the scientific method. The researcher values complementary perspectives of knowledge constructed in multiple ways. The researcher values the pre-defined knowledge base and people's beliefs about the knowledge they hold and know as truth. Generalisations and predictions of knowledge are strengthened by the descriptions of knowledge emanating from the combination of pre-defined truth, and what people hold and know as their truth (Stuart et al., 2017).

3.4 RESEARCH APPROACH

The researcher understood that the complexity of the problem required a different research approach to address the research questions. The overarching methodology was a mixed-method approach with a quasi-experiment embedded in the research design to address the main research question. Three sub-questions were guiding the research study. Table 3.1 outlines the data source, data analysis and how data was interpreted to answer each research sub-question.

Table 3.1: Outline of the research approach and design to research questions

Mixed Methods			
Research Design	Embedded quasi-experimental Design		
	Quasi-experimental		Content Analysis Analysis of responses to open-ended questions
Main Question	***What is the effect of the robotics intervention in Newton's second law of motion in Technical Sciences?***		
Research sub-questions	Question 1	Question 2	Question 3
	1. What is the baseline knowledge of Newton's second law, of Gr 12 Technical Sciences learners?	2. What is the knowledge of Newton's second law of the control group and experimental group after the intervention?	3. What is the difference between the outcomes of an assessment about Newton's second law of the experimental group and the control group after the intervention?
Data Source	Quantitative pre-test	Quantitative post-test	Quantitative pre-test and post-test
Data analysis	SPSS Software - Descriptive statistical analysis	SPSS Software - Descriptive statistical analysis	SPSS Software - Descriptive statistical analysis
Data Interpretation	Inductive and deductive Interpretation of results		

3.4.1 Mixed methods research

Stuart et al. (2017) and Creswell and Creswell (2018) defined the mixed method design as a way to combine aspects of both qualitative and quantitative approaches at different phases of a research study. There is an integration of data in response to the research questions and merging or embedding of qualitative and quantitative aspects, combining the different aspects of data collection instruments, participants, and the approach to evaluation. Multi-dimensional techniques of linking different pieces of data or approaches are combined to build understanding. The benefits of this kind of perspective are that it allows for a more holistic appreciation and understanding of the research (Stuart et al., 2017). Consequently, the approach to knowledge generation is a combination of subjectivity as the participants' perspectives are considered, and objectivity is stranded within detached quantitative data. The values underpinning a mixed-method approach allow the different approaches to complement each other by enabling the researcher to be an observer of and a participant within the phenomena. The justification for using this kind of approach is provided by the results of numerical data for statistical analysis and the narratives and descriptions, which would explain or provide a pathway for exploration for key themes (Stuart et al., 2017).

Evaluation studies have long used the integration of qualitative and qualitative data, and recent studies have since conceptualised this integrative approach and mixed methods. The complexity of attempting to address learner misconceptions and misperceptions in Technical Sciences makes a mixed-method research design a useful approach for this particular study. The purposes of choosing a mixed-method approach may be complementarity, development, expansion, initiation or triangulation. In this study, the researcher proposed the purpose of complementarity by employing different methods to tackle different angles of the same phenomena. In such a case, Chaumba (2013) explains that the goal may be to clarify, enrich, and increase the depth and confidence of the quantitative results by illustrating and expanding interpretations with qualitative data. Through a systematic review of mixed methods approaches in social work, Chaumba (2013) identified promotion and addition of participants' voices and the systematic analysis of events, occurrences, and the findings' validity when employing the mixed methods approach. Chaumba (2013) further highlighted how such an approach was made possible by the strengths of both qualitative and quantitative approaches while limiting some weaknesses of both types of research approaches.

Generally, the strength of drawing on a mixed-method approach is that the limitations of both qualitative and quantitative approaches may be minimised (Creswell & Creswell, 2018). Subsequently, the researcher has access to both types of data. Thus the mixed method approach provides a practical advantage since the researcher may procedurally have a deeper understanding of research questions and problems. In this study, data collection has been strengthened by explaining the quantitative results in light of a thematic analysis of the qualitative data. Perspectives from individual participants contribute to the amplification of experimental data. The mixed-methods design came with its own set of limitations and challenges, including the researcher having to dedicate time for comprehensive data collection and data analysis. The researcher needed to be familiarised with both types of data forms. The researcher had to be able to mix both qualitative and quantitative data appropriately. The mixed-methods design was quite time-consuming; therefore, the researcher needed to manage different data types, quantise the qualitative data, qualitatively analyse quantitative data, and interpret results whether they were conflicting or congruent.

3.5 RESEARCH DESIGN

A research design is defined by Creswell (2014) as a framework that guides the processes of planning, implementation and analysis of a research study. Furthermore, he articulates that these are the plans and procedures for the research that involve several decisions underpinning the study. The research design that the researcher undertook in this study was guided by pragmatist assumptions that informed every decision. The procedure of enquiry included a qualitative test instrument embedded within the quasi-experimental strategy. This study's design logic, articulated in the following sub-sections, was deemed best suited to provide answers to the research questions.

3.5.1 Purpose statement

This mixed-methods study addressed the effectiveness of robotics as an intervention strategy in Technical Sciences. An embedded mixed-method design was used, in which one data set provides a supportive, secondary role in a study based primarily on the other data set. This study used a pre-test and post-test instrument to determine whether there was a significant difference between participants that received robotics intervention in Technical Sciences and those that did not. A secondary purpose was to gather qualitative data in the form of open-ended questions, embedded within the instruments based on the same themes as the quantitative data, that explored the reason for the difference in results between the pre-test and the post-test. The secondary database was collected to provide support for the primary purpose of determining the effectiveness of robotics as an intervention strategy in Technical Sciences. This design's appropriateness is considered when the researcher emphasises the meaningfulness of data when secondary data is embedded within the primary data set (Edmonds & Kennedy, 2017).

3.5.2 Quasi-experimental design

In this study, the quantitative aspect included a quasi-experimental design, which was less rigorous than true-experimental designs. Creswell (2014) posits that experimental research aims to determine whether a certain outcome could be achieved by employing a specific treatment of the phenomena. There were two groups in this quasi-experimental study: One group was provided with the specific treatment and is known as the experimental group. The specific treatment was withheld from the control group and replaced with another kind of intervention. The researcher determined at the end of the experiment whether there was a difference in the two groups.

3.6 RESEARCH STRATEGY MODEL

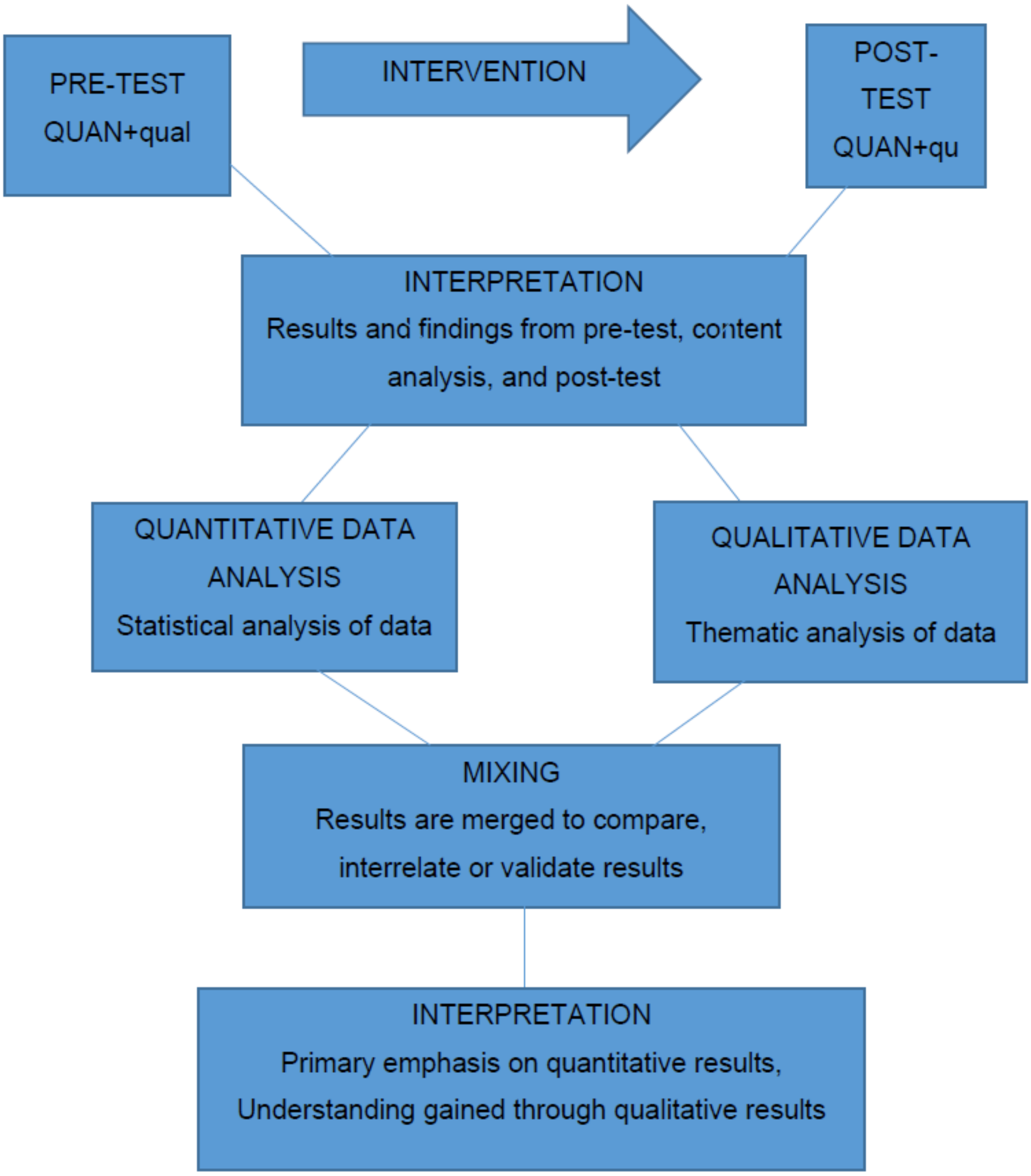


Figure 3.2: Research Strategy Model

The researcher collected mainly quantitative data in the pre-test, while the qualitative data was embedded in the instrument's open-ended questions. The interventions that took place was a social experiment of a qualitative nature, because teaching occurred in both the robotics and traditional intervention classes, albeit using different pedagogical approaches. Traditional intervention classes can be characterized as classes that provide additional instruction to students, target underperforming students, or are conducted by teachers to reinforce challenging concepts that students struggle with. These expanded opportunities offered in traditional intervention classes are differentiated, according to researchers in the National

Education Evaluation and Development Unit (2017), so that learners who are falling behind can catch up and high performing are challenged to achieve even more distinctions. The same instrument was repeated in the post-test and consisted of both qualitative and quantitative data. Triangulation and interpretation of the results occurred methodologically, where both the quantitative and qualitative data were prioritised to give meaning to the outcome of the study. Figure 3.2 describes the embedded quasi-experimental design of this study.

3.7 DATA COLLECTION

The data collection process was important as the integrity of such needs to be maintained for the results of the study to be credible. In the following sub-sections, data collection in the pre-test and post-test is thoroughly explained, with specific mention of the type of data collected and the collection methods.

3.7.1 Pre-test and Post- Test

The study aimed to answer the question:
What is the effect of the robotics intervention in Newton’s Second law of motion in Technical Sciences?

The researcher assumed that an instrument to test concepts and misconceptions of Newton’s Second Law was best suited for this study. Creswell (2014) agrees that collecting different and various types of data best provide a more comprehensive understanding of a research problem than qualitative or quantitative data alone. In this mixed-method study, the researcher tried to draw on data collection strategies from quantitative and qualitative methods, which included test items and open-ended questions embedded within the quantitative test. The data collected included both numbers and words. The study began with a pre-test of 10 multiple-choice questions arranged thematically, with four open-ended questions to collect detailed views of participants to help explain the quantitative test results. Data was collected at the school site, which was a natural setting for the participants, and the threat of the participants experiencing an issue or problem during the study was therefore minimised.

There was moderate participation by the researcher. Palaiologou et al. (2016) described participant observation as a form of qualitative observation where the researcher participates in the natural and/or manipulated environment, which provides holistic descriptions of education practices. The advantage of participant observation is that it allowed the researcher to be immersed in the educational setting (Palaiologou et al., 2016). The duality of the role as a facilitator in the constructivist learning environment also allowed the researcher to understand the contextual factors and characteristics meaningfully to make sense of the data.

The insider's role was embraced during intervention activities when the researcher had to explain how to build and program a robot and guide questions to lead the inquiry in the learner participants. The researcher claimed more of an outsider role once the learners started participating in the activities by themselves, relying intrinsically upon self-directed learning, and extrinsically on collaborative learning with their peers.

Participants were not exposed to a contrived situation, and the researcher conducted the research study in direct face-to-face contact with the participants, which is a major characteristic of research that has a qualitative nature. The researcher reviewed all the data, made sense of it and organised it.

3.8 SAMPLING

In this section, the researcher outlines the sampling process, population and sampling procedures undertaken. A technical school close to the researcher was selected, as they were willing and available. Only part of the population was selected for the intervention group since it requires many resources and a lot of time to include the entire population in the study. Purposeful sampling was used to select learners from the selected technical school who took Technical Sciences.

3.8.1 Population

The target population as defined by Alvi (2016) was accessible and consisted of participants who met the specified criterion, which was a Grade 12 Technical Sciences class following the CAPS curriculum. Asiamah et al. (2017) and Alvi (2016) unpacked the importance of specifying the accessible population in an inquiry. The learners were from a technical school in Mamelodi, Tshwane South District, a population that was accessible to the researcher. The population of concern was Grade 12 Technical Sciences learners, some of which have been taking Technical Sciences since Grade 10, while some have migrated from physical science to Technical Sciences during the course of study before Grade 12. The researcher hoped to understand the specific knowledge, and whether an intervention strategy would strengthen the understanding of Newton's second law, a topic in the Technical Sciences curriculum described in the CAPS document. The study focused on Grade 12 Technical Sciences learners because it is assumed that all teaching and assessment on Newton's second law have been completed and that the participants should have sufficient knowledge to demonstrate the skills and apply their knowledge as expected. Thus, the interventions were not their first encounter with Newton's laws for either of the groups.

3.8.2 Sampling Method

3.8.2.1 Quantitative Data: Combination of systematic and random sampling

The participating school and participants' sampling of the Grade 12 Technical Sciences class learners was convenient and purposeful. The selection of the two groups was random. Alvi (2016) purports that the benefits of systemic random sampling provide a way to get a random sample representative of the chosen population. Although there are advantages to this sampling method, the disadvantages do not derail nor affect the study's validity in any way. The Grade 12 Technical Sciences learners were 42 in total, and all 42 learners agreed to participate in the study. Thus, the researcher divided the class in half to have one experimental group, who participated in the intervention, and one control group, who continued with the Technical Sciences teacher's traditional intervention. The splitting into the two groups was conducted in the following manner:

- From the 42 learners listed alphabetically in an excel spreadsheet, the researcher used the RAND function from Microsoft Excel to assign random numbers to the participants. The list was then sorted according to these random numbers in ascending order. The first 21 participants from the list were then assigned to the control group, and the last 21 in the list were then assigned to the experimental group.

3.8.2.2 Qualitative data: A combination of convenience and purposeful sampling

For the qualitative data collection, questions probing learners' understanding of Newton's Second law were embedded in the pre-test and post-test instrument that required learners to answer fully. Learners who took Technical Sciences as a subject were purposefully selected from the Grade 12 cohort at the identified Technical Highschool. . While abiding by ethical standards, the researcher ensured that each participant voluntarily took part and that they were not forced to participate in any activity they did not want to.

3.8.3 Reviewing the sampling process

Considering that this research study employed various stages in the process of sampling, information is provided in Table 3.1. below, which indicates the participant's information that is relevant for this research study. It was noted in the case selected that learners who take Technical Sciences, also are obligated to take engineering graphics and design (EGD), and they have a choice between electrical technology, mechanical technology and civil technology. Therefore, the researcher further added the participant's subject choice, for the process of building a logical chain of evidence, to match the terminology used by particular classes.

Table 3.2: Participant Information

	Participant Code	Gender	Subject Choice	Term 1 Technical Sciences Marks (100)	Group
1.	EM01	Male	Electrical Technology	33	Control
2.	CF01	Female	Civil Technology	35	Experimental
3.	MF01	Female	Mechanical Technology	27	Experimental
4.	MF02	Female	Mechanical Technology	19	Control
5.	MM01	Male	Mechanical Technology	41	Experimental
6.	CM01	male	Civil Technology	41	Control
7.	MM02	Male	Mechanical Technology	45	Control
8.	MM03	Male	Mechanical Technology	35	Experimental
9.	CM02	Male	Civil Technology	43	Experimental
10.	CF02	Female	Civil Technology	23	Control
11.	EM02	Male	Electrical Technology	28	Control
12.	EM03	Male	Electrical Technology	34	Experimental
13.	CM03	Male	Civil Technology	41	Experimental
14.	CM04	Male	Civil Technology	29	Control
15.	MM04	Male	Mechanical Technology	27	Experimental
16.	MF03	Female	Mechanical Technology	22	Experimental
17.	MM05	Male	Mechanical Technology	33	Control
18.	CF03	Female	Civil Technology	38	Control
19.	MM06	Male	Mechanical Technology	32	Experimental
20.	CF04	Female	Civil Technology	44	Control
21.	CF05	Female	Civil Technology	25	Control
22.	MF04	Female	Mechanical Technology	37	Experimental
23.	EF01	Female	Electrical Technology	38	Experimental
24.	MM07	Male	Mechanical Technology	29	Control
25.	EM04	Male	Electrical Technology	61	Control
26.	EF03	Female	Electrical Technology	37	Control
27.	CM05	Male	Civil Technology	27	Control
28.	CF06	Female	Civil Technology	21	Experimental
29.	EF04	Female	Electrical Technology	38	Control
30.	CF07	Female	Civil Technology	30	Experimental
31.	EF05	Female	Electrical Technology	23	Experimental
32.	CM06	Male	Civil Technology	23	Control
33.	EM05	Male	Electrical Technology	27	Experimental
34.	MF05	Female	Mechanical Technology	49	Control
35.	EM06	Male	Electrical Technology	29	Experimental

36.	MM08	Female	Mechanical Technology	22	Control
37.	CF08	Female	Civil Technology	28	Experimental
38.	EF06	Female	Electrical Technology	46	Control
39.	CF09	Female	Civil Technology	27	Experimental
40.	CM07	Male	Civil Technology	21	Control
41.	EF07	Female	Electrical technology	41	Experimental
42.	CM08	Male	Civil technology	34	Experimental

3.9 DATA ANALYSIS AND INTERPRETATION

In terms of trying to understand “what works’, the researcher sought to quantify results from the pre-test and post-test to identify whether there were any statistical relationships among the variables, differences between the control group and experimental group or any change from before the intervention to after the intervention took place. The researcher also tried to make sense of the data by analysing the qualitative data text to identify any themes or patterns from the open-ended questions that might have emerged (Creswell et al., 2016). Inductive and deductive techniques were used to best address the study's aims and respond to the questions informing the research study.

3.9.1 Quantitative data analysis

The researcher intended to know what the knowledge of the control group and experimental group was before and after the intervention and whether there were any differences between the outcomes of the assessment. The questions that guided this research study required the use of descriptive statistical analysis. Palaiologou et al. (2016) describe the analysis approach that helps with the description and summary of data to allow meaningful patterns and conclusions to emerge, as descriptive statistical analysis. The researcher performed this statistical analysis using SPSS (Statistical Package for Social Sciences) software. A t-test was applied for the two data sets to compare the difference between the outcomes of assessment about Newton’s second law of the experimental group and the control group after the intervention. The researcher aimed to show the difference between the mean of two data sets were statistically significant. Additionally, variance analysis was applied to the data sets to determine the extent of the difference in scores between the control group and the experimental group. To test the null hypothesis, which stated that there is no difference between the control group results and that of the experimental group, the researcher observed the level of significance (p-value). The researcher analysed the frequency distribution, mean, median, mode, range and standard deviation of the two data sets to answer the quantitative questions.

The researcher undertook statistical approaches aimed to answer the questions using descriptive statistical analysis. Using SPSS software, the following was determined:

- Mean of pre-test
- Mean of post-test
- Distribution of marks
- Distribution of marks for post-test
- Standard deviation also is known as the measure of variation for the two groups
- Achievement scores for the control group
- Achievement score for the experimental group
- Comparison between the experimental group and the control group

From the factors determined above, the researcher undertook the deductive interpretation of the results to understand what the results showed, what was important that could be implied from the results, and whether the results could be related to other reported research.

3.9.2 Qualitative data analysis

In this study, the researcher found it appropriate to use content analysis, as it suited the study's purposes. The authors in Palaiologou et al. (2016) define content analysis as an account of the number of times specific words or phrases appear in a text, without specific expectations. The same authors noted that a researcher’s prior knowledge is part of the qualitative enquiry, and may be relevant to the situation. The approach was two-fold: firstly quantizing the qualitative data in effect by coding and categorising it into the themes already embedded in the study, and secondly finding emerging themes that the researcher might not have expected. The latter effectively opened pathways for the data to shape the researcher’s enquiry as it progressed. The content analysis provided a guideline that essentially leads to inductive analysis, which Palaiologou et al. (2016) define as the “recognition of patterns, themes and regularities”. The building of these themes and categories was organised from the bottom up, leading to abstract knowledge and information. The inductive process mandated the researcher to shift focus between the database and the developing themes to establish a broad set of themes.

3.10 QUANTITATIVE QUALITY CRITERIA

Cohen et al. (2018) posit that one of the keys to effective research is validity, which is concerned with a researcher’s instrument's soundness, whether the instrument is a fair indicator of abstract or observable constructs. Whether it measures exactly what is intended to be measured, the truthfulness of the research is known as the validity of the research study. Potential threats to validity were identified beforehand to assure that the robotics intervention and not any other factors affected the outcome of the study, for the researcher to take responsive action. The researcher needed to ensure that such potential threats and the likelihood of them arising, were minimal. Creswell (2014) identifies three types of threats to the validity of a research study: internal validity, external validity and construct validity.

3.10.1 Internal validity

Procedures in the experimental research, experiences or treatments that threaten the researcher's ability to infer accurately from the data about the population and experiment are known as internal validity threats. These types of potential internal validity threats were identified in the study, and the researcher responded instinctively to minimise the threats.

The intervention took place over three weeks, focusing only on one topic. This was an advantage in that several external threats to internal validity were minimised. There were no major events that unduly influenced the outcome beyond the experimental treatment as far as the researcher is concerned; therefore, history was not a threat. The other threats to internal validity were identified and addressed as follows:

1. Regression

   When participants who have extremely high or extremely low scores are selected for the experiment, their score will naturally change to regress towards the mean, threatening the internal validity. Participants were randomly selected and did not have extreme scores before the intervention. The duration of the intervention was for short intervals, reducing the effect of systematic regression effects.

2. Selection

   Certain characteristics, such as intelligence or giftedness, may influence participants to certain outcomes if they are selected based on such criteria. Random sampling was used in this research study to avoid selection bias so that the probability of learners being selected from different groups is increased.

3. Diffusion

   When participants from the control group and the experimental group communicate with each other about the intervention and the test, outcomes may be influenced as a result. The intervention took place after school hours when participants from the control group had no contact with the experimental group. However, the researcher cannot verify whether participants did not communicate during school hours, narrating their experiences to the control group.

4. Compensatory/ resentful demoralisation

Unequal benefits may arise due to only the experimental group receiving treatment. The researcher continued with the teaching of robotics to the rest of the control group to ensure no resentment due to unfair treatment arising.

5. Compensatory rivalry

   Since they did not experience the treatment, the control group participants may have felt that they were not valued. The researcher ensured that participants understood the study's nature and that they had to participate in groups at a time. Another advantage with the site selected was that the participants were used to conducting their practical academic activities in different groups and at different times, especially since they all participated in the three different streams of the technology subject, and hence were used to one group participating in a certain activity before the others.

6. Testing

   Pre-tests at the beginning of the quasi-experimental study may produce effects other than that arising from the intervention, such as participants remembering their pre-test responses or questions for later testing. The time interval between the pre-test and post-test was approximately three weeks, while other academic assessments occurred during the gap. The researcher believed it was sufficient time to minimise the threat of testing on internal validity

7. Instrumentation

   Changes to instrumentation may impact the scores on the outcome. The researcher used the same instrument for the pre-test and the post-test

3.10.2 Construct validity

The concepts that were intrinsic to the test instruments and intervention were concepts based on Newton's second law of motion. Hence, in designing the instrument, the researcher considered construct validity threats to try to mitigate them. The researcher followed the two stages outlined in Cohen et al. (2018) to address construct validity. First, the constructs were identified as tension force, frictional force, gravitational force, and Newton's second law equation variables. Experts, who included the researcher's supervisor and co-supervisor, guided the researcher, making comparisons with tests such as the Force Concept Inventory (FCI). Secondly, the test instruments were categorised into four themes which were pre-determined to solely address the constructs. Threats to construct validity were identified and addressed in the flowing ways:

1. Operationalisation of the construct and its indicators

   An intelligence test on its own is a significantly discriminating construction of aptitude (Cohen et al., 2018), therefore the researcher included open-ended questions at the end of each section to probe the learners' thinking and understanding of the concept.

2. Failure to keep out external factors

   None of the learners who participated in the intervention had other involvement in extra tuition, such as private lessons, for Technical Sciences. The researcher sought out such information from the participants to determine if any other factors outside the intervention would affect the results of the study. Most of the participants only indicated extra intervention for mathematics and technical mathematics, which occurred less than five times for the intervention duration.
3. Confounding constructs

   In Newton's Second Law of Motion, the main variables are net force, acceleration and mass. These three concepts need to be considered together with frictional force, tension force, normal force, and gravity force when applying the law and solving complex problems.

   The concepts tested in this research study were based on the exit level outcomes of a Grade 12 (NQF level 4) learner due to the Technical Sciences CAPS policy's nature. It is important to note that the intended learner for Technical Sciences is a more technical, occupationally inclined learner, which means that the focus should be on the theoretical concepts rather than the application and articulation of the concepts mentioned above.

3.10.3. External validity and generalisability

Creswell (2014) posits that when incorrect inferences are drawn from the sample data for other settings, situations or persons, external validity threats arise. This particular research study focused only on a small group of learners from a township in Pretoria, east of Gauteng Province. Due to the participants that took part in the robotics intervention's narrow characteristics, the researcher could not generalise the results or make claims about other groups since the results were restricted to Technical Sciences learners from that group only. Only one race was represented in the participants, but they were all from different cultural backgrounds. The researcher did not conduct additional experiments with other learners since they did not take Technical Sciences as a subject; therefore, interaction and selection of treatments posed a threat to external validity.

Additionally, the interaction of setting and treatment was also identified as a threat to external validity. The researcher conducted the study in a previously disadvantaged community where the socio-economic status of the environment comprised the poor, middle class and young citizens in a melting pot of political influence. Inferences cannot be made to generalise the results as the township has its own set of unique characteristics apart from other towns or areas. The researcher did not replicate the study in a different area; therefore, the results are only applicable to that particular technical school in the specific township.

Lastly, since the intervention exclusively focused on one topic for a short period of three weeks, the results cannot be generalised to past or future situations. It was imperative that the study only took place in the second term since Newton's second law is delivered and assessed in term one. If the researcher attempted the study earlier, the learners might still not fully have grasped Newtons second law's basics, which would not make the intervention valid per se, as it would be a teaching strategy rather than an intervention strategy. The study could also not have been feasible in the third term, as learners would be disinterested in pursuing a topic they would not be assessed on in the third term, and would rather focus on curricula serving the required purpose for their benefit. Therefore the interaction of history and treatment was a threat to external validity as the researcher did not conduct the intervention repeatedly at another time.

Table 3.3 summarises all the threats to external validity, the description of the threats and the reasons why they are threats due to the actions the researcher could not take.

Table 3.3: Threats to external validity

Types of threat	Description	Reasons
Interaction of selection and treatment	The results of the data cannot be generalised to other races or learners with different socioeconomic backgrounds	The researcher did not repeat the experiment with additional groups of different characteristics
Interaction of setting and treatment	The experiment occurred in one setting; thus the results cannot be generalised to other settings	The researcher only experimented with one site
Interaction of History and treatment	The data and results of this experiment cannot be generalised to past or future events	The researcher did not replicate the study at later times nor was there a pilot study conducted beforehand

3.10.4. Reliability

Reliability demonstrates the internal consistency, precision and accuracy of an instrument or research I (Cohen et al., 2018). f the same instrument is used repeatedly, or the same research is replicated several times, it should yield the same consistent results. The instrument used for the pre-test and the post-test drew on the principles of the Force Concept Inventory (FCI), items from assessment instruments designed by the DBE moderators, and items designed by the researcher’s supervisor. The data collection instrument's length was fairly adequate, as there were ten multiple-choice questions and four open-ended questions. The instrument was not too long, risking participant fatigue, or too short as it addressed the four constructs the researcher intended to address. The heterogeneity of the group, however, was not entirely reliable. Although there was an almost equivalent number of males to females, their entire population consisted of one race. Thus the data is not reliable for inferences to other cultures or ethnic groups.

3.11 QUALITATIVE QUALITY CRITERIA

“Qualitative validity means that the researcher checks for the accuracy of the findings by employing certain procedures, while qualitative reliability indicates that the researcher’s approach is consistent across different researchers and different projects” (Creswell, 2009, p. 190). In qualitative research, there are multiple views of socially constructed reality. This warrants the need to check for validity in whether the instrument measures what it intends to measure, including the accuracy of the data collection and instrumentation when one needs to deduce outcomes and understand what the results mean (Cohen et al., 2018). The researcher was part of the world being researched, and complete objectivity was not possible. Hence, the learners' perspectives as participants were equally important and as valid as that of the researcher. In this study, the researcher sought to represent the Technical Sciences learners being investigated impartially; thus, there was no generalisability of the results, which made external validity irrelevant.

3.11.1 Trustworthiness and credibility

Credibility, transferability, dependability and confirmability are the four fundamental extensions of trustworthiness in the categories of validity and reliability (Palaiologou et al., 2016). The researcher ensured that data was represented in a transparent manner where re-analysis could readily be conducted to validate the findings. Negative instances, such as participants not participating in the post-test, were reported in the data analysis.

3.11.2 Legitimisation

Considering the design of this study was of mixed methods like its approach, the quality criteria in this kind of design warrants for a different approach as well. Some authors (Cohen et al., 2018) define the quality criteria requirements in mixed methods as legitimisation instead of validity. This is to overcome the problems inherent to mixed methods design such as the representation of data, legitimation and the integration of both quantitative and qualitative methods. The different types of legitimisation and how the researcher has tried to address them in this study are listed in Table 3.4.

Table 3.4: Types of Legitimisation and the researcher's actions in response

Type of Legitimisation (Cohen et al., 2018)	**In response, the researcher took the following actions**
Sample integration The effect of integration of the sample size on the quality of inferences made	*Quantitative sample:* The researcher sampled 50% of the population *Qualitative sample:* The researcher selected sample-rich sites to draw inferences from that data Effect: The sample size for both qualitative and quantitative were effective in drawing inferences and deducing results effectively
Weakness minimisation Compensating of weakness from one approach by the strengths of the other approach, as well as suitably weighting of both strengths and weakness	The weakness of the quantitative results was that the results could not be explained, but the richness of the explanations from the qualitative worksheets and embedded questions within the pre-test and post-test added to the meaning of the results
Sequential Order effects from inferences made from qualitative to quantitative data collection and analysis, or the effects of inferences made from quantitative to qualitative data collection and analysis	In this research study, the qualitative data was embedded in the quantitative test instrument. Data collection and analysis occurred concurrently in a parallel method. The results of the quantitative instrument can be understood from the responses of the learners in the open-ended questions.
Paradigmatic mixing How successful the mixing of ontological, epistemological, axiological, methodological and rhetorical beliefs and practices in yielding useful results, particularly if the paradigms are in tension with each other.	This study followed a pragmatic approach, where multiple truths are concerned with knowing what works.

3.12 ETHICAL CONSIDERATIONS

This study was intended to understand whether robotics would be an effective intervention LTSM in Technical Sciences which is taught in high schools for learners under the age of 18 years. It was important for the researcher to follow ethical protocols while undertaking the study. The following subsections describe how ethics was an important factor to be considered in the study.

3.12.1 Informed consent

Before commencing with the study, the researcher visited the school to have a meeting with the principal and some School Governing Body (SGB) Members. Weeks later, follow up visits ensued regarding the appropriate time to commence with the study so as not to encroach on the study schedule and yearly teaching plan. Once the researcher obtained approval from the principal and the SGB, consent forms were issued out to learners for the parents to consent. The researcher explained the purpose of the study, the contents of the consent forms and the implications of assenting to the study. The researcher waited before all the forms were signed and copies of the forms were archived in the school's office, before commencing with the pre-test.

3.12.2 Ethical requirements from the University of Pretoria

Transparency was maintained throughout. The learners were able to see their scores from the pre- and post-tests after the intervention was conducted. The following steps were taken to ensure that the study conformed with the ethical standards laid down by the Ethics Committee of the University of Pretoria:

- The name of the school involved was kept anonymous.
- The results were anonymous concerning the participants' names.
- The research proposal, along with all data collection tools, was presented to and approved by the University of Pretoria's Ethics Committee before data collection. The process of data collection commenced months later after approval of the research proposal and instruments. This was due to the researcher considering the school and taking the time to explain the research process to the school and participants.
- Approval and informed consent were sought from the participants and parents. Approval for the study was obtained from the University of Pretoria (Appendix 1) and the Gauteng Education Department (Appendix 2). The participants were presented with a consent form and assent form with a brief introduction to the study. The principals' permission and that of the SGB were sought (Appendix 3). Parents' consent forms and learners' assent forms were completed and signed (Appendix 4).

3.13 LIMITATIONS

The research study was conducted only at one school in the Gauteng province, and thus cannot be generalised to the rest of the provinces in South Africa. The study was also limited in participants as it only focused on one ethnic group.

4 CHAPTER FOUR: QUANTITATIVE RESULTS AND DATA PRESENTATION

4.1 INTRODUCTION

In the previous chapter, the researcher described the methodology and research approaches used to collect data. In this chapter, the results from the quantitative data will be analysed. The researcher undertook the data collection process at a technical school in Tshwane South district in Pretoria during May 2019. The researcher collected data from the control and experimental groups before and after the intervention. The process of data collection involved a pre-test, which was administered before the robotics and traditional interventions, and the same test was administered as a post-test after the interventions to both the control and the experimental groups. Pseudonyms were used for each of the 42 participants. The researcher analysed all quantitative data using SPSS software, and content analysis was used to analyse the qualitative data. Figure 4.1 illustrates the quantitative data collected and how it will be presented in this chapter.

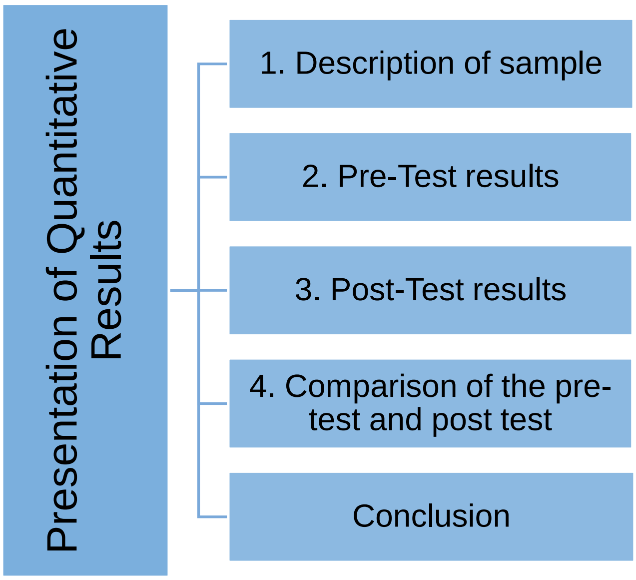


Figure 4.1: Outline of presentation of data

4.2 DESCRIPTION OF SAMPLE

A total of 42 Technical Sciences learners participated in the study. They were assigned to an experimental group (n = 21) that took part in the robotics intervention, and a control group (n = 21) that continued with conventional extra classes. All the participants completed both the pre-test and the post-test, but only the experimental group of learners completed the robotics intervention worksheets.

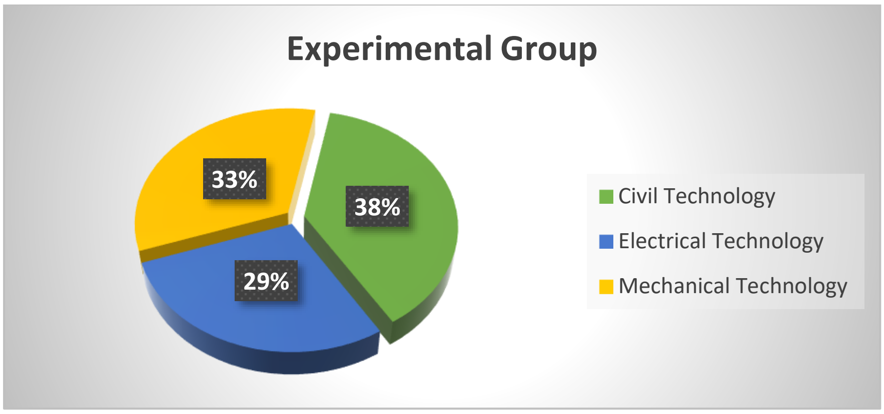


Figure 4.2: Description of the Experimental group

A total of 11 female (52.4%) and 10 males (47.6%) formed part of the experimental group. A third of the participants (33%) had mechanical technology as their elective subject, and 38% were civil technology learners. Electrical technology learners constituted 29% of the experimental group. The rules of combination for elective subjects in a technical school were explained in Chapter 3.

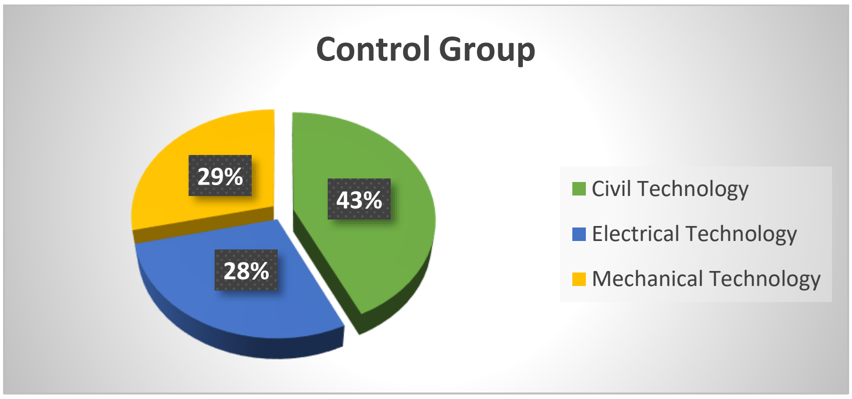


Figure 4.3: Description of the Control group

In the control group, nine female (42.8%) and 12 males (57.2%) continued with extra classes and did not participate in the robotics intervention. An equal number of learners had mechanical technology (29%) and (28%) as their elective subjects, while most learners (43%) were civil technology learners.

4.3 BASELINE KNOWLEDGE OF PARTICIPANTS

In this section, the researcher presents a quantitative overview of the results and responses from the participants in the pre-test. The participants all completed a pre-test (Appendix A), that consisted of ten (10) multiple-choice items and four (4) open-ended questions. As a final score, only the multiple-choice items were considered and therefore the maximum achievement score was ten (10) marks for the quantitative results. It was important to the researcher to know what the mean, median and mode of the pre-test were to understand the general features of the distribution of the pre-test results. Table 4.1 displays the parametric statistics concerning the number of participants in the group (N), maximum marks of the test (Max), mean (M), standard deviation (SD), skewness and kurtosis value, which provide meaning to the raw marks from the study.

The researcher viewed kurtosis and skewness as an essential measure to test the normality of the distribution of data in the statistical analysis. Since a t-test would be used after the post-test to determine the level of significance, it was important to know the distribution of the data. SPSS (Statistical Package for Social Science) software was used to perform all the statistical calculations.

Table 4.1: Statistics of Pre-Test outcome before the intervention

Group	N	Max	Median	Mode	M	SD	Kurtosis	Skewness
Experimental	21	10	3	3	3.42	1.2	1.96	-0.95
Control	21	10	3	2	3.19	1.6	2.74	1.43

Before the intervention, the mean test scores of the experimental group was *M* = 3.42, *SD* = 1.2 and the mean of the control group was *M* = 3.19, *SD* = 1.6. This shows that most of the participants in both the control group and the experimental group achieved scores that are average (around the mean) and that there is not much variability between the scores. The participants from the experimental group can be considered as representative of the whole population because there are no extreme scores that will cause regression towards the mean (the scores are evenly distributed around the mean).

Kurtosis and skewness were measured for determining the internal validity of the results, as explained by Cain et al. (2017), one needs to understand whether the data satisfies the normality assumption. Relative to the normal distribution, kurtosis can be defined as a measure of whether the data are heavy-tailed or light-tailed (Cain, Zhang, & Yuan, 2017). T-tests for independent samples assume there is a normal distribution of the data, therefore understanding kurtosis and skewness helps the researcher know how severe the skewness is, what type of skewness it is (right-tailed or left tailed), and what can be done about it or what the consequences are, (Cain, Zhang, & Yuan, 2017). The data set of the control group showed a higher kurtosis value of 2.74 while the experimental group had a value of 1.96, which means that the experimental group data was more normally distributed than the control group. The experimental group pre-test was moderately skewed with skewness of -0.95 while the control group was highly skewed with a skewness of 1.43. The descriptive analysis of the data will be performed again on the post-test results to determine the kurtosis and skewness before performing the t-test after the intervention. A kurtosis value of less than 3.0 strengthens the validity of the results as the threat of regression is overcome (Cain, Zhang, & Yuan, 2017). The researcher observed that since the data for the experimental group was normally distributed, the test scores of high achieving learners and low performing learners would be expected not to regress (or tend toward the mean), which would strengthen the validity of the results.

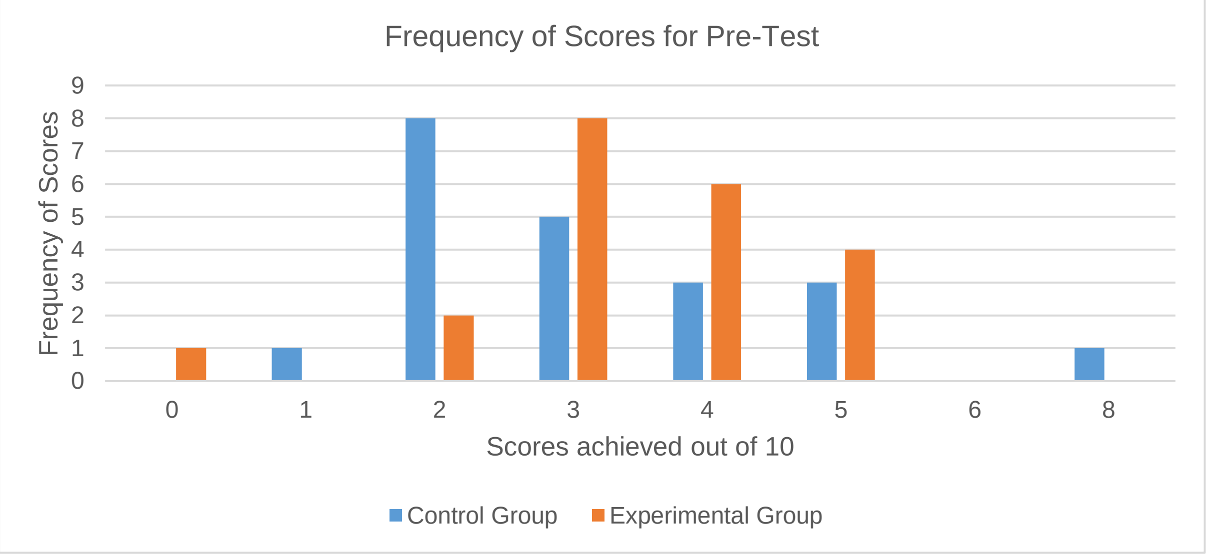


Figure 4.4: Frequency of Scores for Pre-Test

The highest mark achieved out of a maximum possible of ten (10) was eight (8) for the control group, and five (5) for the experimental group. The lowest mark achieved was one (1) for the control group and zero (0) for the experimental group. The sum of the test scores of the experimental group was 72, while the sum of the scores for the control group was 67. The mode was three (3) for the experimental group, and two (2) for the control group. The median of both groups was three (3), which was noted by the researcher because the interest of this research study was to test whether the difference in learning outcomes after the robotics intervention was significant.

The pre-test item analysis (see Fig 4.5) showed that the item with the most correct responses from the control group was item N2M4. Item N2M4 required the participants to calculate the net force with the given applied force, frictional force and constant acceleration. The item with the most correct responses was item FT1 for the experimental group, with sixteen participants from the experimental group answering correctly. This item required the participants to compare tension in two cables. The items with the lowest correct responses were item FGN1, item FF2 and item FT2. Item FGN1 required the participants to determine the angle of the inclined plane using the relationship of the force of gravity and the force applied. A discussion of THE items and the responses to items follows in Section 4.4.2.

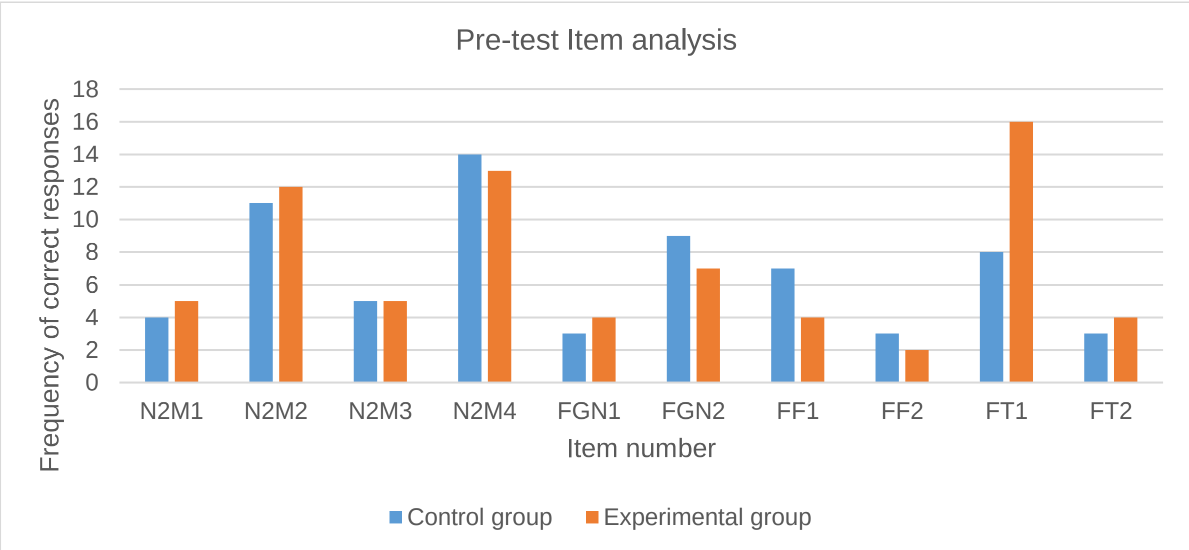


Figure 4.5: Pre-Test Item Analysis

4.4 Knowledge of Participants after the interventions

In this section, the researcher presents an overview of the results and responses from the participants in the post-test. The mean, median and mode of the data will be discussed to characterise the general features of the distribution of the post-test results. Table 4.2 displays the parametric statistics of the post-test concerning the number of participants in the group (N), maximum marks of the test (Max), mean (M), standard deviation (SD), skewness and kurtosis value, which provide meaning to the raw marks from the study.

Table 4.2: Statistics of the post-test after the intervention

Group	N	Max	Median	Mode	M	SD	Kurtosis	Skewness
Experimental	21	10	5	5	4.57	1.43	0.81	-0.83
Control	21	10	3	3	3.19	1.16	4.69	1.67

After the normal extra classes, the mean test score of the learners from the control group, *M* = 3.19, *SD* = 1.16, was the same as the mean score in the pre-test, *M* = 3.19, *SD* = 1.6. After the robotics intervention, the mean test score of the learners in the experimental group, *M* = 4.57, *SD* = 1.43, was higher than the mean score before the robotics intervention, *M* = 3.42, *SD* = 1.2.

The data set of the control group showed a high kurtosis, a value of 4.69, which means that it had outliers and were thus heavy-tailed relative to the normal distribution. The data set of the experimental group showed a very low kurtosis, a value of 0.81, which means that the data was more normally distributed, and in line with the pre-test normal distribution assumption. The experimental post-test data was moderately skewed with skewness of -0.83, while the control group data remained highly skewed with a skewness of 1.67.

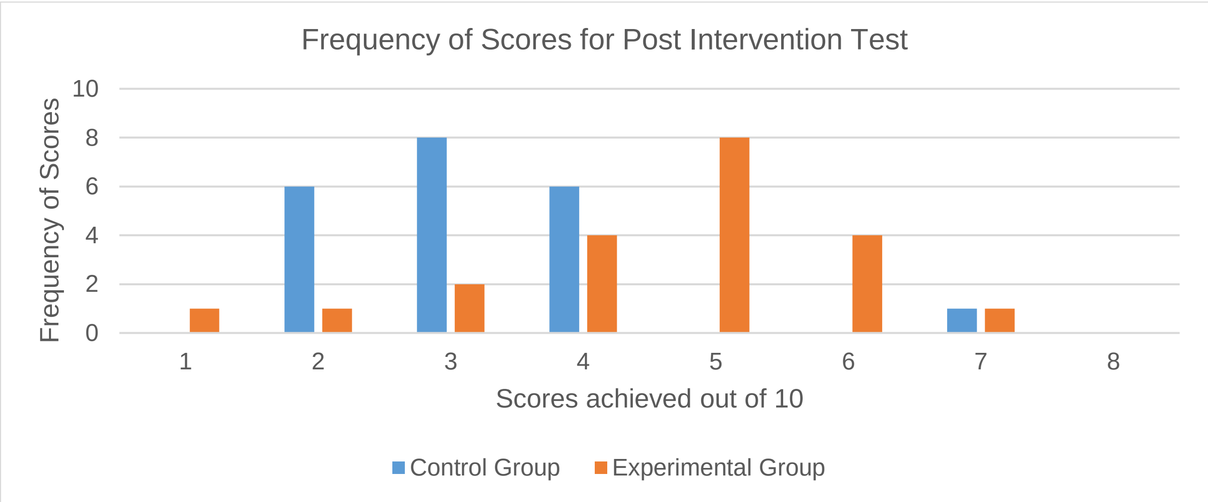


Figure 4.6: Frequency of Scores for Post Intervention Test

The highest mark achieved out of a maximum possible of ten (10) was seven (7) for both groups. The lowest mark achieved was two (2) for the control group and one (1) for the experimental group. The sum of the test scores of the experimental group 96, while the sum of the scores for the control group remained at 67. Both the median and mode of the experimental group increased from three (3) to five (5), while the median of the control group remained at three (3). The mode of the control group increased from two (2) to three (3).

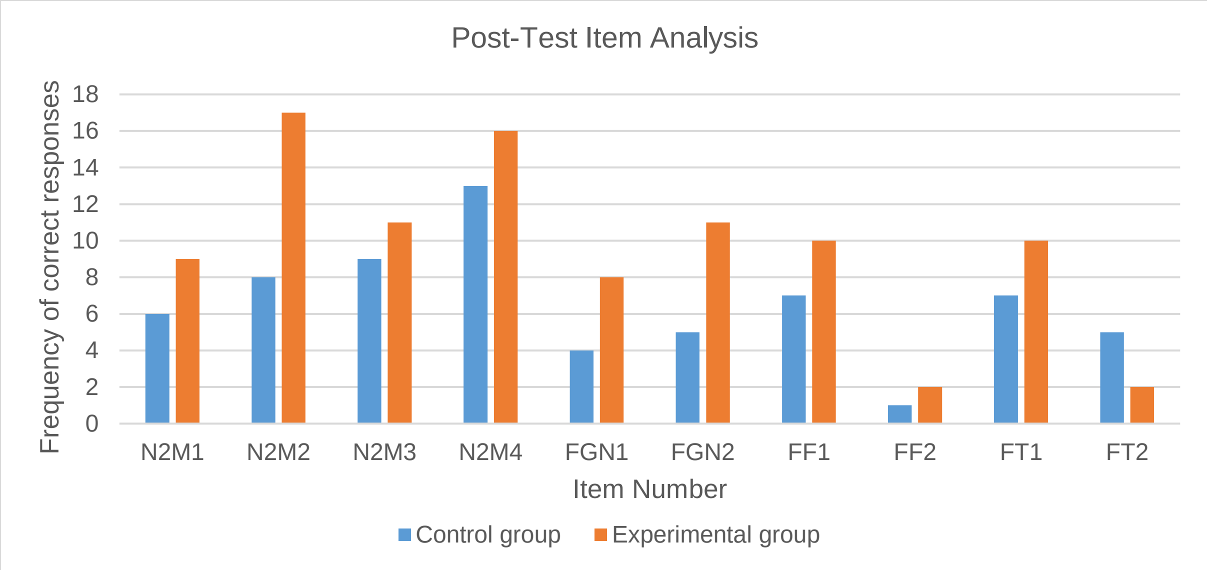


Figure 4.7: Post-test item analysis

The post-test item analysis (Figure 4.7) showed that the item with the most correct responses from the control group was item N2M4, which was also the most correctly answered in the pre-test. Item N2M4 required the participants to calculate the net force with the given applied force, frictional force and constant acceleration. The item with the most correct responses was item N2M2 for the experimental group, with seventeen (17) participants from the experimental group answering correctly. This item required the participants to determine the effect of a decreasing net force on acceleration and velocity. The item with the lowest correct responses was item FF2 with one (1) correct response for the control group, and only two (2) correct responses from the experimental group. This item tested the participants' understanding of frictional force and the effect on the motion of a crate. A discussion of items and the responses to items follows in Section 4.4.2.

4.5 COMPARISON OF RESULTS: PRE AND POST INTERVENTION

It was important for the researcher to compare the pre-test and post-test results of the participants, to ascertain the effectiveness of the robotics intervention. The comparison of results is discussed first BY looking at the statistical parameters, and secondly, a comparison is made in the performance of participants for each item.

4.5.1 Comparison of statistical parameters

Statistical calculations were performed using SPSS software to determine the mean (M), Standard Deviation (SD) and the mean difference (MD) of both the control group and experimental group and are shown in Table 4.3.

Table 4.3: Comparison of statistics before and after the intervention

Group	Test type	N	M	Median	Mode	SD	MD
Control Group	Pre-test	21	3.19	3	2	1.6	0.0
	Post-test	21	3.19	3	3	1.16	
Experimental Group	Pre-test	21	3.42	3	3	1.2	1.15
	Post-test	21	4.57	5	5	1.43	

There were 21 participants in each group, as seen in Table 4.3, N = 21. Before the intervention, the mean of the control group was *M* = 3.19, *SD* = 1.6, and after the intervention, the mean was the same with a value of *M* = 3.19, *SD* = 1.16. The mean difference (*MD*) of the control group was found to be *MD* = 0. This shows that the normal extra classes were not effective in improving the quantitative test scores. Before the intervention, the pre-test mean of the experimental group was *M* = 3.42, *SD* = 1.2., and the mean of the group increased to *M* = 4.57, *SD* = 1.43 after the robotics intervention. The mean difference of the experimental group, which was obtained by comparing the mean of the experimental group before and after the intervention, was found to be *MD* = 1.15.

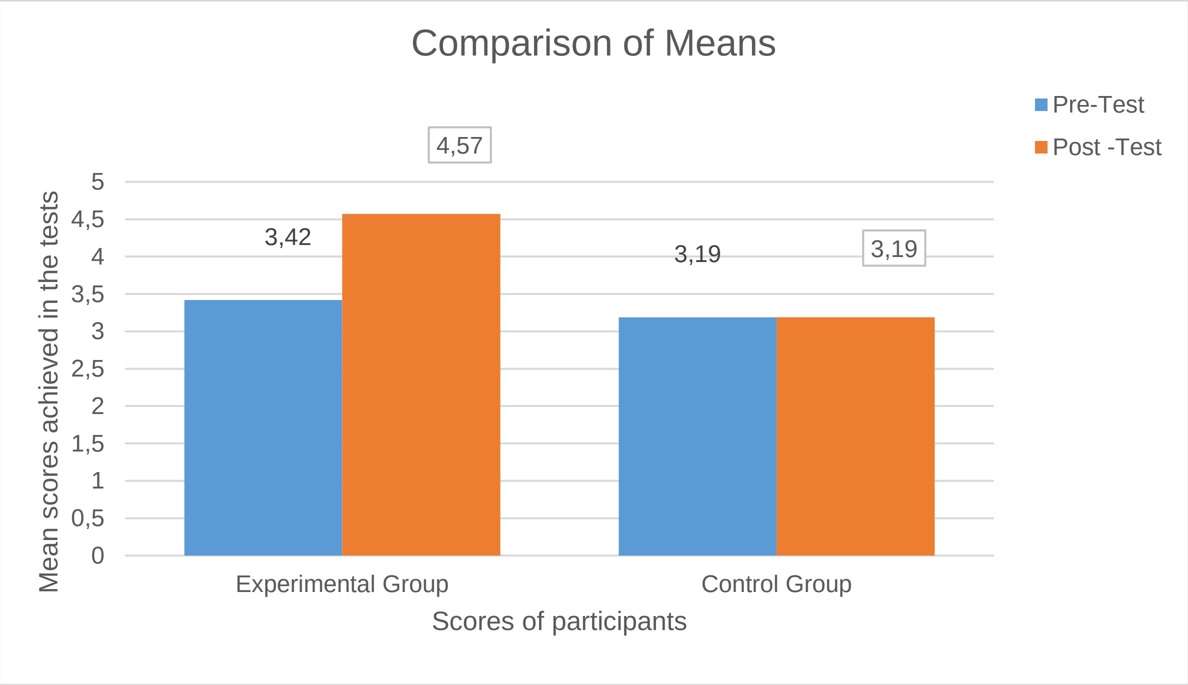


Figure 4.8: Comparison of means before and after the intervention

Figure 4.8 shows the mean scores achieved by the participants in the experimental group that had the robotics intervention and the control group without the robotics intervention. The experimental group performed better than the control group as they achieved a higher mean after the intervention. The researcher used SPSS software to calculate the confidence intervals of the two groups. According to Thompson (2002), confidence intervals (CI) can be used to assess statistical significance and allows an estimation to be made on the range of values for the true population. The robotics intervention appeared to have affected the experimental group who achieved a higher mean in the test after the intervention *M* = 4.57, 95% CI [3.92, 5.22], than the pre-test which was before the robotics intervention, *M* = 3.42, 95% CI [2.87, 3.97]. For the control group, the traditional intervention classes did not have a pronounced effect on the differences between the means in the pre-test, *M* =3.19, 95% CI [2.42, 3.92], and the post-test, *M* = 3.19, 95% CI [2.66, 3.72].

Table 4.4: Independent samples t-Test

Independent Samples Test									
	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Equal variances assumed	.66	.430	3.42	40	0.001	1.31	0.44	0.69	1.93
Equal variances not assumed			3.42	38	0.001	1.31	0.44	0.69	1.93

An independent sample t-test was performed using SPSS software. The independent t-test showed that the difference in post-test scores between the control group (n = 21, *M* = 3.19, *SD* = 1.16) and the experimental group (n = 21, *M* = 4.57, *SD* = 1.43) were statistically significant, *t*(40) = 3.42, *p* = *0*.001. The inferential statistics used to assess the equality of variances for the control group and the experimental group was Levene's Test. Levene's test assesses the assumption that variances are equal, (Muijs, 2004). In Table 4.4, it is shown that indeed the variances between the control group and the experimental group are approximately the same. This makes it possible for the researcher to be able to compare the two groups because when the variances are approximately the same, it means that the data of the two samples are spread almost equally. The Sig. (2-Tailed) value in the results was *p* = *0.*001*,* which is less than 0.05. A *p-value* of less than 0.05 indicates that there is a significant difference between the two groups. Therefore, we can conclude that there is a statistically significant difference between the mean of the test scores between the control group and the experimental group. The *Null Hypothesis one (H01),* that was stated in Chapter 1 is therefore accepted as there is a significant difference between the test results of learners who participate in the robotics intervention program and those who do not participate in the robotics intervention.

4.5.2 Item analysis

An item comparison was made to determine the performance of all the participants in each item. Figure 4.9 depicts the frequency of scores for each item before and after the interventions of both groups.

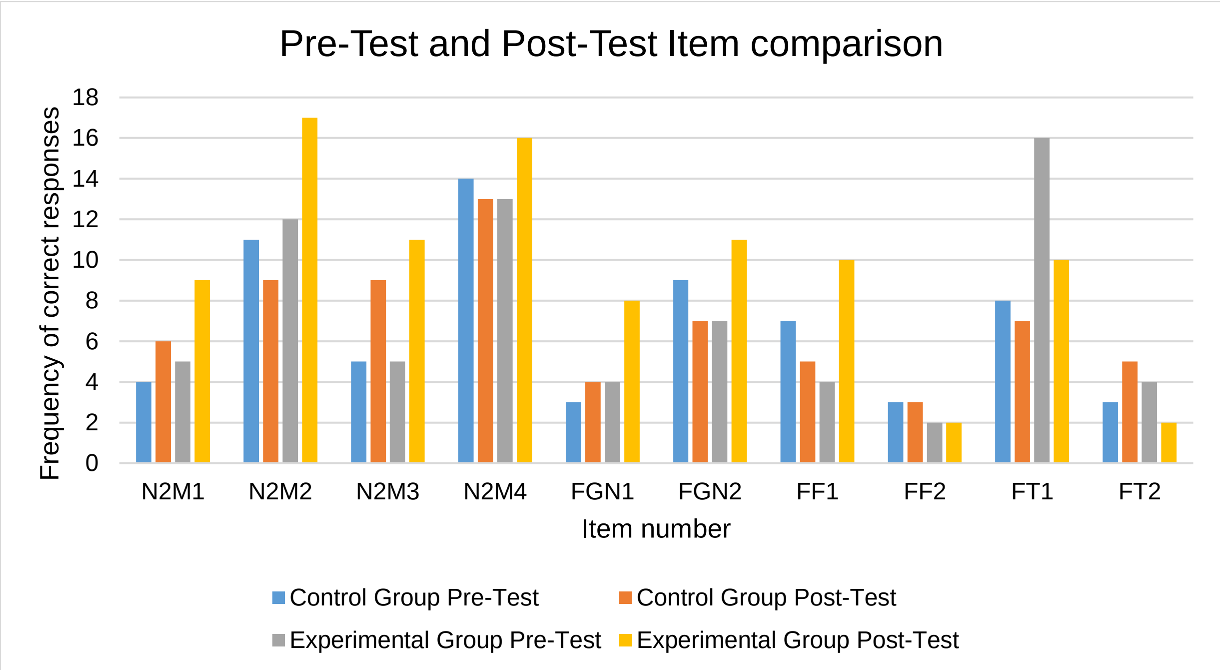


Figure 4.9: Item comparison for the pre-test and post-test

The items were analysed according to item facility (IF), item discrimination (ID) and distractor efficiency as mentioned in studies done by Toksoz and Ertunc (2017), and Siri and Freddano (2011). A paper by Toksoz and Ertunc (2017) define item facility as the extent to which an item is deemed easy or difficult for a particular group of test-takers. Therefore, the item facility was taken as a measure of item difficulty and was calculated using the formula stated below:

Equation 4.1: Item Facility

$$Item\ Facility\ (IF) = \frac{number\ of\ learners\ answering\ the\ item\ correctly}{Total\ number\ of\ learners\ responding\ to\ that\ item}$$

Understanding Item facility enabled the researcher to make judgements based on the performance of participants in the items. Toksoz and Ertunc (2017) posit that an item that is too easy or difficult implies that it does not enable one to differentiate between a high ability and low ability group of test-takers. Items that are considered easy have an item facility of 0.75 – 1.0, while average difficulty items range between 0.25 – 0.75, and hard items have an item facility of below 0.25.

The results were also analysed according to the item discrimination, which is the extent to which an item differentiates between learners of generally high abilities and those who have lower abilities, (Toksoz & Ertunc, 2017). The authors of the same study also posit that one can determine if an item discriminated between the low and high ability group of test-takers if an item gets correct answers from most of the high ability group of test-takers and incorrect answers from most of the low ability test takers.

An item is considered highly discriminating if it has a value close to 1.0 and an item is considered to be a low discriminator if its value is closer to zero, (Toksoz & Ertunc, 2017). The items were then analysed according to how the responses were distributed among the distractors. Distractors should be considered an important part of an item as Toksoz and Ertunc (2017) and Siri and Freddano (2011) posit that there is a relationship between the distractors learners select and the total test score. Distractor quality impacts the performance of learners on a test item and should appeal to low scorers who have not mastered the concepts, whereas high scorers should seldom select the distractors.

The results of Figure 4.9 will be discussed under the next subsections according to the items that did not show improvement after both interventions, the item that showed the most improvement, and the item with the highest correct responses.

4.5.3 No improvement after intervention

The item comparison for the pre-test and post-test showed that the items where participants from both groups did not improve were items FF2 and FT1.

Item FF2: No improvement for either group

FF2 A long rope is attached to a crate. A dog pulling at the other end of the rope manages to move the crate across a flat surface of ice. The friction between the ice and the crate can be ignored. Read the following statements about the force applied by the dog on the rope and the motion of the crate.

1. If the dog applies a constant force, the crate will maintain a constant speed.
2. If the dog releases the rope when the crate is on the move, the crate will maintain a constant speed.
3. If the rope breaks the crate will move slower and stop.
4. If the rope breaks the crate will stop immediately.

Which of statements(s) above is/are true?

A	Only 3 is true
B	Only 2 is true
C	Only 1 and 2 are true
D	Only 1 and 3 are true
E	Only 1 and 4 are true

When is friction helpful? When is friction a problem?

Figure 4.10: Item FF2 in the test instrument where participants did not show improvement

Item FF2 had the lowest correct responses and showed overall poor performance from both groups. In the control group, only three (3) learners answered correctly before and after the traditional intervention classes. The results of the experimental group also did not change for this item as only two (2) learners answered correctly before and after the robotics intervention.

Looking at the respondents more closely, the researcher noted that it was not the same participants that answered correctly before and after the intervention. In the control group, only participant EM01 answered correctly before and after the intervention. Participants MF05 and CM07 answered this item correctly in the pre-test but failed to answer correctly in the post-test. Participants CF02 and EF04 from the control group did not answer correctly in the pre-test but improved and responded correctly in the post-test. In the experimental group, the two participants who answered correctly in the pre-test were participants MF03 and EM06, and only participants MM06 and CF08 answered correctly in the post-test.

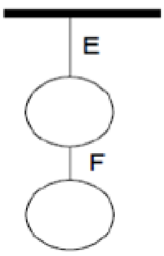
In terms of distractor efficiency, most participants in the control group (28,5% in the pre-test and 47,6% in the post-test) selected option D. Option D was also the most prevalent in the experimental group (42,8% in the pre-test and 38% in the post-test). This showed that option D was a good distractor of the item. Thus, the researcher inferred that most of the participants in both groups believed that if the dog applies a constant force, the crate will maintain a constant speed and if the rope breaks the crate will move slower and stop. This is true because if the rope breaks the crate will continue to move since friction can be ignored in the given scenario (as it follows from Newton's first law of motion).

The only true statement in the given scenario is that if the dog releases the rope when the crate is on the move, the crate will maintain a constant speed. Participants who selected this correct option (Option B) show that they understand what follows from Newton's first law – a body will remain at rest, or continue in constant motion in a straight line unless acted upon by an external force.

The average item facility of item FF2 was found to be IF (FF2) = 0.12, which means this item was found to be very difficult by participants from both groups before and after the intervention. High ability learners failed to answer the item correctly contrary to the expectations.

Item FT1: no improvement for both groups

FT1 Two identical chandeliers are suspended from cable **E** attached to the ceiling and cable **F** attached between the chandeliers, as indicated in the diagram below.



Which ONE of the following relationships between the tension, TE, in cable **E**, and the tension, TF, in cable **F** is correct?

A	TE > TF
B	TE < TF
C	TE = TF ≠ 0 N
D	TE = TF = 0 N

When and why is tension different in the same string at two different points?

Figure 4.11: Item FT1 in the test instrument where participants did not show improvement

Item FT1 of the test instrument showed a decline in the performance of both groups. In the control group, eight (8) participants answered correctly before and seven (7) participants answered correctly after the traditional intervention classes. There was a decline of 4,7% in the performance of the control group, and only four (4) participants, (CF02, CM04, CF05 and EF03) showed consistent performance as they answered correctly before and after the traditional intervention classes. The performance of the experimental group also declined from 16 participants to only ten (10) participants answering correctly after the robotics intervention. This was a decline of 28,5% in the performance with seven participants, (MM03, CM03, MM04, MM06, MF04, EF01 and EF05), consistently answering correctly in this item before and after the robotics intervention.

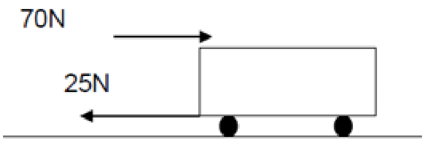
Option B was the second most common answer, after option A, which showed that the other two options were not very good distractors for this item. The item required learners to interpret the given information, draw a free body diagram and apply Newton's Second law to arrive at the correct answer. The decline in performance for both groups for this item was concerning. The average item facility for this item was IF (FT1) = 0.51, which means it was just average – not too easy and not too difficult. The results need to be further investigated according to the open-end responses of the participants, which will be reflected in Chapter 5.

4.5.4 Most correct responses after the intervention

The item with the most correct responses from the control group was item N2M4, with 13 correct responses after the intervention. This was a decline as 14 learners answered correctly for this item in the pre-test.

Item N2M4: most correct responses form the control group after the intervention

N2M4 A woman pushes a trolley in a supermarket with a horizontal force of 70 N. During the motion, a frictional force of 25 N acts on the trolley. The trolley moves with a constant acceleration.



The net force acting on the system is:

A	45 N.
B	25 N.
C	70 N.
D	95 N.

Figure 4.12: Item N2M4 in the test instrument

Participants MF05, MF02 and EF04 answered correctly for this item in the pre-test, but incorrectly in the post-test. Participants EM02 and CM05 only answered correctly after the intervention. The experimental group performed better for this item as 13 participants answered correctly in the pre-test and 16 participants answered correctly after the robotics intervention.

The distractors for this item were generally not effective, as the option most favoured was the correct option A. Option C was an ineffective distractor as neither the participants from the control group nor the experimental group chose option C after the intervention. The average item facility calculated for the pre-test and post-test of both groups was found to be 0.67 for Item N2M4. The participants in the experimental group found this item much easier than the control group and the Item facility for only the experimental group was found to be 0.76 after the robotics intervention. Toksoz and Ertunc (2017) suggest that items such as item N2M4 may motivate low achieving learners as they are considered easy items. The item could be classified as a cognitively lower-order item because participants were given the applied force (in the horizontal direction) and the frictional force, and were required to determine the net force acting on the system moving with constant acceleration. Understanding the implication of Newton's second law of motion and vector addition substantiates why Item N2M4 had the most correct responses for the control group.

The item with the most correct responses for the experimental group was item N2M2, with 17 correct responses after the intervention. This is an increase from only 12 participants who were able to answer this item correctly before the robotics intervention in the experimental group.

Item N2M2: most correct responses from the experimental group after intervention

N2M2 An object is moving to the right while a net force is acting on the object to the right. The net force decreases steadily but is not yet zero. Which row describes the effect this has on the magnitudes of the acceleration and the velocity of the object?

	Acceleration	Velocity
A	increases	increases
B	decreases	increases
C	remains the same	remains the same
D	remains the same	Increases

Figure 4.13: Item N2M2 in the test instrument

Participants CM03, EF05, MF03 and EM06 from the experimental group could not answer item N2M2 correctly even after the robotics intervention. The distractor efficiency for this item was very low, specifically for option A and option D, as the responses were concentrated towards option B which is the correct answer. Item N2M2 from the test instrument probed the participant's understanding of the relationship between net force and acceleration, and what this acceleration means in terms of velocity.

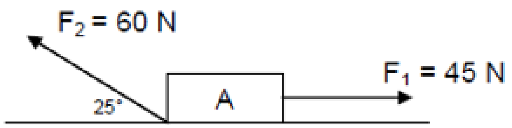
However, the researcher noted that learners from the experimental group showed improvement for this item. In the experimental group, the participants found this item very easy after the robotics intervention as the item facility value was IF (N2M2) = 0.81. In contrast, the learners from the control group did not find this item easy as the calculated item facility for the control group after the traditional intervention was found to be IF (N2M2) = 0.45.

4.5.5 Improvement after intervention observed

The item where participants showed the most improvement was item N2M3 for the control group, and items N2M3 and FF1 for the experimental group. For item N2M3, the control group improved from five (5) participants to nine (9) participants responding correctly in the post-test. The experimental group improved from five (5) to eleven (11) participants responding correctly for item N2M3.

Item N2M3: Improvement after intervention observed

N2M3 Object A is at rest on a frictionless horizontal plane as indicated in the diagram below.



If the forces act on the object as shown in the diagram, the object will ...

A	accelerate to the right.
B	accelerate to the left.
C	move at a constant velocity to the right.
D	move at a constant velocity to the left.

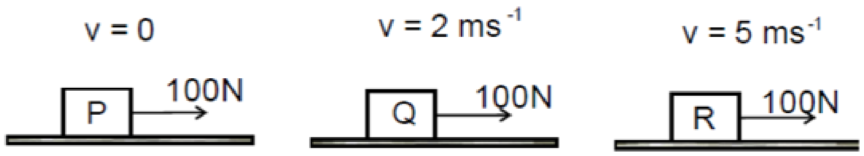
Figure 4.14: Item N2M3 in the test instrument

There was an improvement of only four participants from the control group (EF04, CF04, MM07 and CM06), who responded correctly for this item after the traditional intervention. Seven participants from the experimental group (MM04, MM06, EF05, EF07), (CF01, MM01 and CF09), improved and responded correctly to this item after the robotics intervention.

Option D and option A were the second most selected options, after option B. Therefore, there was a high distractor efficiency for this item, while it showed the most improvement. The Item facility of this item for both groups was 0.24 before the intervention, and 0.48 after the intervention. The researcher classified Item N2M3 as middle-order cognitive demand as it required the participants to interpret the given information and apply their knowledge. The participants needed to first apply their mathematical knowledge by calculating the horizontal component of force F_2, and determining from the net force whether the object will accelerate or move at constant velocity in either direction. The researchers of the Force Concept Inventory (FCI) conducted by Hestenes et al. (1992) proposed that some learners are not able to discriminate between velocity and acceleration and use the terms interchangeably. Participants who selected option D proved they were unable to discriminate between velocity and acceleration, and therefore there was a good distractor efficiency for this item to enable the researcher to understand some of the common misconceptions held by learners that are supported by the literature.

Item FF1: Improvement after intervention observed

FF1 Three boxes are being pulled across surfaces with applied forces as indicated. Blocks that are in motion, move with constant velocity.



Rank the magnitudes of the **frictional forces** acting on the boxes :

A	$F_P < F_Q < F_R$
B	$F_P < F_Q = F_R$
C	$F_P = F_Q = F_R$
D	$F_P > F_Q > F_R$

Figure 4.15: Item FF1 in the test instrument

The experimental group also showed improvement for item FF1, from four (4) correct responses in the pre-test to ten (10) correct responses after the robotics intervention. The researcher noted, however, that it was not the same respondents that answered correctly in the pre-test and post-test. Only participant CF09 showed consistent performance in this item before and after the robotics intervention.

The researcher classified item FF1 as an item of middle-order cognitive demand. Participants first had to interpret the given information from keywords in the problem statement, and understand that constant velocity means the acceleration is zero. The item had an average item facility of 0.31, which showed moderate difficulty. This is further supported by the reasonably good distractor efficiency of items A and D, which were the options most selected after option C. Most participants (7 out of 21) in the experimental group selected option D in the pre-test and one participant did not attempt to answer the question. Participants who selected option D believe that block B, with v = 0 $m.s^{-1}$, has the greatest magnitude of frictional force acting on it, while block R, with v = 5 $m.s^{-1}$, has the lowest frictional force acting on it. These learners believe the object with the lowest velocity has the greatest frictional force.

4.6 CONCLUSION

In this chapter, the quantitative results were presented. The results were discussed according to the relevant statistical parameters, which described the general features of the distribution of the data from the pre-test and the post-test. There was a general indication from these findings that the mean test scores of some learners improved after the robotics intervention. The item analysis further enhanced preliminary inferences that there was an improvement in some items after the robotics intervention, while other items showed that neither of the interventions was effective. Furthermore, the quantitative results showed that the Null Hypothesis one (H01) can be accepted as there is a statistically significant difference in the test results of learners who participated in the robotics intervention program to those who did not participate in the robotics.

Both the robotics intervention and traditional intervention focused on activities of motion. In line with the intervention, the items that showed the most improvement after the intervention were items N2M2 and N2M4, which were motion problems. Items FT1 and FT2 were not problems of motion, and although there was an in improvement in the responses for item FT1, participants did not perform well in item FT2. In the next chapter, the researcher will discuss the qualitative results of the study, which are the responses to open-ended questions that required participants to describe their understanding of acceleration, net force, frictional force, gravitational force and the force of tension.

5 CHAPTER FIVE: QUALITATIVE RESULTS AND DATA PRESENTATION

5.1 INTRODUCTION

In the previous chapter, the researcher presented the quantitative results of the study. In this chapter, the analysis of the qualitative results will be discussed and interpreted. Figure 5.1 illustrates how the qualitative data was analysed, and henceforth will be presented in this chapter.

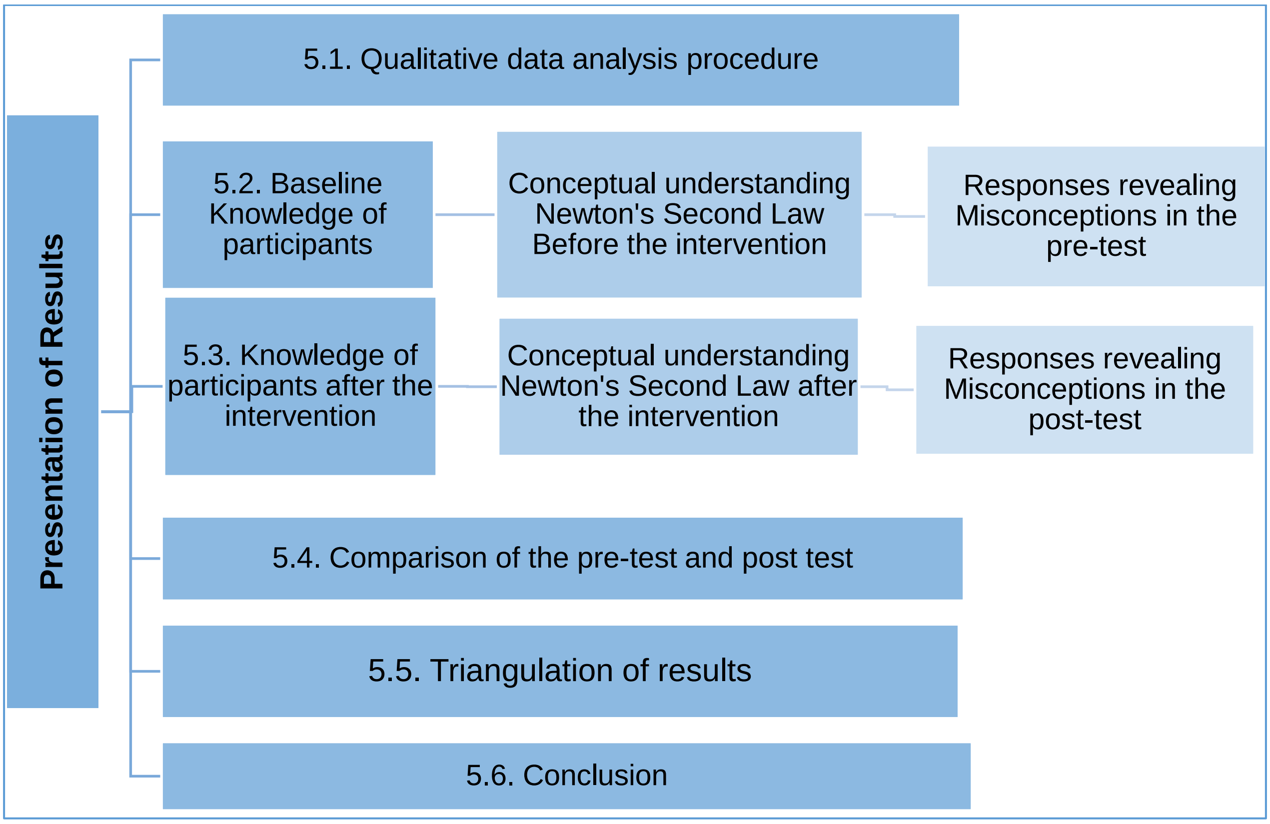


Figure 5.1: Outline of presentation of data

5.2 DATA ANALYSIS – PROCEDURE

The procedure followed for analysing the data will be discussed first, after which the presentation of the data follows. The researcher engaged with the data deductively, approaching the data from a more general to particular understandings of the participants.

The researcher began with manually re-typing the participant's responses verbatim in an Excel spreadsheet, whereby the responses were then grouped into the four qualitative items to be analysed. This was followed by unpacking the qualitative pre-test results and identifying whether any responses were revealing sound conceptual understanding for each of the themes, namely acceleration, net force, frictional force, forces on an incline and tension force.

The researcher then analysed the responses revealing misconceptions. The procedure was repeated for the results of the test after the intervention. The pre-test and post-test responses were then compared in the third phase of the process. This phase included analysing responses from participants in instances where a participant gave the correct response in the multiple-choice item, but a wrong explanation or wrong answer in the open-ended questions.

i. Analysis of results using the proposed conceptual framework

The conceptual framework that guided this research study was the Cognitive Refinement Instructional Approach (CRIA) by Lemmer (2018) that has been discussed extensively in the second chapter of this research study. A bottom-up conceptual change approach was incorporated for conceptual refinement to occur as a means to narrow the gap between learner's intuitive ideas and scientific concepts. The four principles foundational to the CRIA which were incorporated during the research study are the following:

a) Relevant reproductive resources of experiential knowledge – robotics kits were provided to the participants (discussed in the methodology of the research study in Chapter 3);
b) Gradual construction of knowledge by directing participants to connect new and existing information – robotics intervention (as explained in Chapter 3 of this research study);
c) Acquisition of physics knowledge through different activities and contexts (Discussed in Chapters 4 and 5 of this research study); and
d) Awareness of participants' understanding and misconceptions to advance learning (Chapter 5 of this research study).

The analysis of the results will thus be guided by the last two principles of the theoretical framework to determine the effectiveness of the intervention as well as the conceptual change of the participants.

5.3 BASELINE KNOWLEDGE OF PARTICIPANTS

The qualitative analysis of the learners' responses will be presented in this section. A paper by Tuder and Urban-Woldron (2013) explained that although a learner may answer correctly in a test because they have a certain kind of mechanics knowledge, it may not necessarily mean that the learner has the right conceptual understanding. The open-ended questions required the learners to describe their understanding of net force, frictional force, tension force, gravitational force, acceleration and velocity.

The researcher colour-coded the results according to the following classification:

- Green: The answer is correct with evidence of sound conceptual understanding;

- Yellow: The answer displays some level of conceptual understanding but is incomplete;
- Orange: the answer is incorrect and reveals a misconception or there is no evidence of sound conceptual understanding; and
- Blue: Learner stated, “I don’t know/ I don’t understand.”

The classification of responses was done by the researcher and verified afterwards by an expert science educator.

The discussion will start with the baseline knowledge of the mentioned concepts, followed by a discussion of the identified misconceptions for each item. The researcher considered that the participants do not speak English as their home language, and thus this may influence their ability to express their knowledge or thoughts clearly.

Item N2M1

N2M1 A **constant** net force, F, is applied to a crate which moves along a frictionless horizontal surface. Which ONE of the following quantities remains constant while force F acts on the crate?

(A)	the rate of change of velocity
B	the momentum
C	the work done on the crate
D	the kinetic energy

Do you think there will be a time when the crate will stop? If not, how would you slow down the crate or stop the crate in motion? Explain your answer.

Figure 5.2: Item N2M1 in the pre-test

Newton’s first law of motion states that an object will remain at rest or continue at constant uniform velocity unless an external or unbalanced force acts upon it. Item *N2M1* tested the participant’s ability to recognise that the laws do not exist in isolation, and Newton’s second law follows from the first law. This concept was addressed in Activity 1 of the robotics intervention (Appendix B) which expected participants to build a robot, and program the robot to travel different distances and utilise different acceleration, with constant mass. This concept was addressed in Problem 1 of the traditional intervention classes (Appendix D

).

Table 5.1: Responses of participants to Item N2M1 in the pre-test

ITEM N2M1: How would you slow down the crate or stop the crate in motion? Explain your answer				
Control Group			**Experimental Group**	
CF02	no the crate will not stop. To stop or slow down the crate a non-zero force must be applied on the crate		MF01	it won't stop until the is a frictional force applied and keeping on increasing the rough surface
MM05	no, the crate will be stopped if friction is applied		MM06	NO. unless an unbalance force act in an opposite direction or I can say by applying a force in the opposite direction
CF03	no, you can slow down the crate by decreasing the acceleration		MM01	by decreasing the net force applied on the object and the acceleration will decrease too
CF04	the more you accelerate the more the speed if the is a less you apply a frictional force that will slow down the crate and it will stop		MM03	to decrease the motion of the crate, the frictional force must be applied to a crate
EM04	No. Introduce a surface that friction. Have air resistance opposite the applied force that is more than the net force		MF03	Yes it will stop so there won't be any need to slow down the crate. No, it won't stop because there is no friction on the surface so in order to slow it down, we apply friction
CM05	BY making the surface rough/ adding a frictional force on the surface		CF07	Another force has to be applied that will cause the destructive interference for the crate to stop
MM08	no, because there is no friction. There must be a friction in order for the crate to slow down		EM06	No the wont be anytime as when You want to stop it you will have to apply opposing force.
CM07	It will stop because the surface is rough not smooth, so the rough movement will decrease the movement		EF07	There will be a time when the crate will stop
MF05	the crate will continue while it remains constant. If the crate breaks by slowing it down the crate will stop moving		CM08	No, because when the crate will stop, which means rate of change of velocity
EM01	By so doing the stand still crate to perform in order to settle the mals in the		CF01	yes a constant net force is applied to a crate moving along a frictionless
CM01	no, to stop the crate you must lift the crate when it will not move		EF05	No, iIll have to increase the mass of the object
MM02	YES. Because of will be using a stopwatch to count the time when the crate stops		EM05	Yes because it will reach the point where the crate is constant
CM06	yes when you decrease the velocity then the crate will stop moving		CM02	no, the crate cannot stop on its own. You have to stop it by decreasing the force. Then it will slow down or stop. Yes, there will be a time where it will stop
EM02	I would put something heavy inside the crate so that it could move slowly, and also put a bricks, or a box in front of the crate		EM03	when work is done or by decreasing a force and also by stopping to work
CM04	to stop the crate I will have to remove the applied force		CM03	by applying a force that is big than the inertia of an object
EF04	Yes, it will stop if the is no pressure applied to move the crate		MM04	there will be fnet, we will have to remove the applied force
CF05	yes the crate will stop		MF04	yes. There will be a time the crate stop because of constant net force that is applied to a crate.
MM07	no, if the crate is being pulled or pushed with a force that is constant on a horizontal surface will not stop unless the acting force is being removed		CF08	Yes, because when you push it forward it will stop obviously
			CF06	No, to slow down the crate the net force must be decreased
			CF09	I don't understand
			EF01	I don't know

While the majority of the participants' answers were not in line with the expected answer, CF02 from the control group gave the response of:

> *"No the crate will not stop. To stop or slow down the crate a non-zero force must be applied on the crate".*

The learner (CF02) did not specify the direction of the force, but the answer was in line with Newton's First Law of Motion.

As seen in Table 5.1, in the experimental group's responses, participant MM06 understood that an unbalanced force needs to act in the opposite direction:

> *"No. Unless an unbalance force act in an opposite direction or I can say by applying a force in the opposite direction"*

The response from participant MM06 shows an understanding of Newton's First Law, and that an unbalanced force can act in any direction therefore participant MM06 emphasised that the force must act in the opposite direction to stop the moving object. Participant EM04 revealed that he had the correct conceptual understanding because he stated that one can introduce a surface of friction for the crate to move on.

Certain misconceptions were identified from the participant's responses in the pre-test. The following section highlights the misconceptions and identified responses that do not show understanding of the scientific concepts being tested from the participant's baseline test.

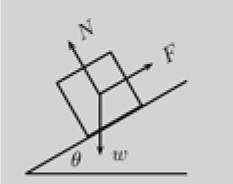
In participant CM06's response: "Yes, when you decrease the velocity then the crate will stop moving", it was not explained exactly how the decrease in speed was to be realized.

Participants EM04, CM05, and MM05 from the control group, as well as participants MF01 and MM03 from the experimental group had the incorrect practical concept of friction and thought that frictional force can be applied like an applied force, and it shows that the participants do not follow the correct scientific reasoning. Liu and Fang (2016) indicated that such responses are a reflection on the participants' lack of skill to apply what has been learned in the classroom to real-world situations because one cannot simply "add a frictional force" to a moving object. Instead of the participants reasoning that one needs to "add a frictional force", the participants should have answered, "when the crate moves on to a rough surface, a surface with friction, then the crate will slow down". Six (6) of the learners (28.6%) accounted for friction as the force needed to slow down the crate.

Participant CM04 from the control group articulated one of the most common misconceptions to moving objects - that all objects eventually stop moving when the force is removed: "*To stop the crate I will have to remove the applied force*". Research conducted by Liu and Fang (2016) revealed that some learners have the misconception that an object in motion has a continuous force acting on it, and this kind of misconception demonstrates that the learner cannot apply what was learnt in class to real-life situations.

Item FGN1 (pre-test)

FGN1 A box is held stationary on a smooth plane that is inclined at angle θ to the horizontal



F is the force exerted by a rope on the box, w is the weight of the box and N is the normal force of the plane on the box. Which of the following statements is correct?

A	$\tan\theta = \frac{F}{w}$
B	$\tan\theta = \frac{F}{N}$
C	$\cos\theta = \frac{F}{w}$
D	$\sin\theta = \frac{N}{w}$

Why do you think the box remains stationary?

Figure 5.3: Item FGN1 in the test instrument

The second open-ended item, shown in Figure 5.2, tested the participants' conceptual understanding of forces on an incline, which was addressed by Activity 2 in the robotics intervention (Appendix B) and Problem 2 in the traditional extra classes intervention (Appendix D). The responses of some of the participants are recorded in Table 5.2, and the misconceptions identified are subsequently discussed.

Table 5.2: Responses of participants to Item FGN1 in the pre-test

ITEM FGN1: Why do you think the box remains stationary?			
Control Group		**Experimental Group**	
CM01	because it is held by the rope	CM03	because the applied force is not enough to move the box
CF02	all the forces acting on an object are equal/ at equilibrium. Normal force is equal to fg perpendicular. F applied if equal to Fg parallel	CM02	because there is not net force applied to the box. So that is why the box is at stationary
CF04	because if the is no force applied the box will remain stationary unless acted upon	CF07	the force exerted by rope and the weight are the same. The forces have the same net force. The force exerted by the rope of weight and the normal are the same which makes the box stationary
EM04	the fore F is of equal magnitude to w perpendicular but act in opposite direction	MM06	because the friction force is equal to the applied force, so they cancel each other
MM08	because there is nothing moving the box or there is no force applied	CF01	stationary is on a smooth plane at angle theta to the horizontal
EM01	because the stationary has its own weight	MM04	the normal force is equal to the weight of the box
MF02	because the box is not moving	MF01	no the is a force acting horizontal to the smooth surface that is inclined therefore it will move
MF05	because a box is held stationary on a smooth plane that is inclined at the angle theta to the horizontal surface	MM01	because there is force exerted that denies the object to movie
MM02	because of the box is constant that is why it will remain stationary	MM03	no, because theres also a force parallel to the inclined plane acting on an object in the oppoisite direction of F

EM02	the box will move slowly until it reaches zero and it will remain constant		EM03	because of a smooth plane that is inclined at angle theta to the horizontal and it also our angle theta indirectly to the force
CM04	force is not applied on the box		EF07	the box remains stationary because it is inclined at an angle horizontally
MM05	because there is not friction		CM08	because force is not applied on the box
CF03	because the box is at a horizontal surface		MF03	the box remains stationary because there is normal force and its constant
CF05	yes		MF04	because of a box is held stationary on a smooth plane and that is inclined at angle theta to the horizontal
CM05	yes because the velocity is directly proportional to the net force		EF01	because there is no rough surface
EF04	the would be no force applied to the object		CF06	because it is held with an angle
			EM06	because fg=fn and they are on frictionless surface at an angle of inclination
			EF05	because the phone is incline
			CF08	it's because it's shows about (answer D) and here there are asking about that
EF06	I don't understand		CF09	I don't understand

When the forces are in equilibrium, it means the sum of the forces is equal to zero. This means that the acceleration is zero and the object in this question will remain stationary. From the control group, none of the participants understood and answered the question correctly. Participant CF04 revealed some understanding, but should have specified "no *nett* force acting on the box".

Three participants in the experimental group (CM02, CF07 and MM06) showed some understanding of the concept of forces in equilibrium, although they articulated it differently in their responses and did not always show a realisation of which forces should be equal to each other.

Participant CF07 did not have the correct conceptual understanding:

> *"The force exerted by rope and the weight are the same. The forces have the same net force. The force exerted by the rope of weight and the normal are the same which makes the box stationary."*

The learner (CF07) had an idea that certain forces needed to be equal but did not take the direction of the forces into account.

Participant MM06 said: *"Because the friction force is equal to the applied force, so they cancel each other".* The answer is partially correct. The participant has some sense that forces should cancel one another but did not realise that friction is negligible on a smooth surface.

A common misconception about forces is that if anything is stationary it has no forces acting on it, i.e. an object that has balanced forces or no force acting on it must be stationary. In the question about normal force and gravitational force, only participant CM03 understood that the net force is equal to zero, in other words, all the forces acting on the object are in equilibrium. Although his answer is correct, the participant does not state the full conceptual reasoning.

Three learners from the control group (CM04, MM08, EF04), and one learner (CM08) from the experimental group had the misconception that there is no force applied on the object. Thus, they have the common misconception that *"If anything is stationary it has no forces acting on it. An object that has balanced forces or no force acting on it must be stationary"* (Liu & Fang, 2016).

Although the response rate to this question was low (eight participants left the space blank), the learners that did respond accounted either friction or the lack of friction as the reason for the box remaining stationary. One participant (MM05) responded:

> "*Because there is not friction.",*

At the same time, some participants accounted the incline or angle as the reason the box remains stationary, for example in participant EF07's response: *"The box remains stationary because it is inclined at an angle horizontally".* The responses are consistent with the results from the study by Liu and Fang (2016) which indicate learners are unable to contextualise the concepts of Newton's law that are learnt in the classroom and apply them in new situations.

ITEM FF2

FF2 A long rope is attached to a crate. A dog pulling at the other end of the rope manages to move the crate across a flat surface of ice. The friction between the ice and the crate can be ignored. Read the following statements about the force applied by the dog on the rope and the motion of the crate.

1. If the dog applies a constant force, the crate will maintain a constant speed.
2. If the dog releases the rope when the crate is on the move, the crate will maintain a constant speed.
3. If the rope breaks the crate will move slower and stop.
4. If the rope breaks the crate will stop immediately.

Which of statements(s) above is/are true?

A	Only 3 is true
B	Only 2 is true
C	Only 1 and 2 are true
D	Only 1 and 3 are true
E	Only 1 and 4 are true

When is friction helpful? When is friction a problem?

Figure 5.4: Item FF2 in the pre-test

Item FF2 tested the participants' conceptual understanding of the effect of the absence of friction, which was addressed by Activity 3 in the robotics intervention and Problem 3 in the traditional extra classes' intervention. The responses of some of the participants are recorded in Table 5.3, and the misconceptions identified are discussed.

Table 5.3: Responses of participants to Item FF2 in the pre-test

ITEM FF2: When is friction helpful? When is friction a problem?				
Control Group			**Experimental group**	
CF02	friction is helpful in tar roads, making cars to be able to turn and stop. Friction is a problem when driving it finishes off your tyres		CF07	friction is helpful when the is a gentle slope. Friction is a problem when we have steepness
CM04	friction is helpful when we need an immediate stop but it's a problem when we carry heavy objects on a rough surface		MM06	friction is helpful when you want to stop a certain thing when it's in motion. And there is no force acting on it. Sometimes friction is a problem because it requires a certain amount of force to move an object depending on the friction, the greater the direction the more the force needed
MM07	friction is helpful when stopping an object and it's a problem when pushing or pulling an object		MM01	when we need to stop an object friction is helpful or when moving at high acceleration friction is needed to stop. When pulling a crate in a friction surface, it requires you to increase your applied force to move quicker.
EM04	it is helpful by assisting us to move forward or keep cars moving forward. It is a problem when we are pulling an object as more force need to be applied		MM03	friction is helpful when used to decrease an objects motion so that it may not exceed the speed limit. Friction is a problem when it reduces the total speed of an object or when it causes inertia
CM01	the firction is a problem on ice, when we want the crate to stop. The friction is helpful when we release the rope on ice		MF04	friction is helpful if the dog applies a constant force, the crate will maintain a constant speed. Friction is a problem if the rope breaks the crate will move slower and stop
EM01	when theres friction at all between this particular crates or object		CF01	when the rope breaks the crate will move slower and stop
MM02	friction is helpful because of it makes contact with the gravitational force. So that the things can move freely. And friction is a problem because of if tere is no contact force with the gravitational force things cant move freely		MF01	friction help a car to brake and also generate heat. friction can tear a rope when it is on duty of something urgent
			CM02	the friction can be helpful by stopping or by helping the cart to stop. It can be a problem when it is frictionless
EM02	the dog will applies a certain force to the crate when it pulls the crate		EM03	friction is helpful when the dog applies a constant force and is a problem when the rope breaks the crate
MM05	friction is helpful when the dog pulls the rop horizontally and it will be a problem when the surface is rough		CM03	friction is helpful when the surface is smooth and a problem when its hard
			MF03	friction is helpful when its applied to the object. It becomes a problem when there is force applied and the object is at motion , friction shouldn't be applied
CF04	when you push or pull it's a problem when applied to a ruff surface		EF01	friction is the thing that causes movements
CF05	friction is a problem on a rough surface and it is helpful on a smooth surface or places like ice		CF06	friction is a problem when that object has to be touched. Friction is helpful because it makes an object move smoothly
CM05	friction helps when a crate is horizontal. Friction is a problem when you want a crate to move faster		EF05	when the object is moving. When the object moves at constant velocity
EF04	friction is helpful when you are trying to slow down the accelerating. Friction is a problem when you are pulling/pusing a heavy object on a rough surface		EM05	friction is helpful mostly when its cold or when you want to start a fire with two stones
CM06	you are approaching a stop and helps to maintain balance. When on a smooth surface		EM06	friction is helpful to decrease speed of moving things and it's a problem when it is less cause it causes what is on the motion to keep going forward unless it act upon an unbalanced force
MF05	the friction is helpful to make the create constantly. Friction is a problem when it maitain a constant speed. The create might not stop moving		CF08	a friction is helpful when it comes to the speed because the friction will stop the speed. A friction is a problem when you pulling something and you are in a hurry and that thing will go slower while you are in a hurry
MM08	friction is helpful when you want to slow down or stop an object. Friction is a problem when you		CF09	when the surface is rough

EF06	friction is helpful when the rope breaks the crate will go slower and stop. The problem will be that the friction will stop moving	EF07	friction is helpful when the rope breaks and it is a problem when the crate moves slower
CM07	friction is helpful when the surface is rough and it will be a problem only if the surface is smooth	CM08	friction can attach to other friction which means friction can be applied to any rope
CF03	I am not sure	MM04	no clue

Many participants did not realise that friction does not always hinder motion but that there are certain instances where friction needs to be present for objects to be able to move. This critical aspect of friction forces needs to be taught to learners using real-life examples such as tyre thread designed to maximise friction (traction) between the tyre and the road or when one tries to walk across a surface there needs to be friction between your feet and the surface. Another example of friction being useful is when heat needs to be produced. The misconception about the usefulness of friction is evident in the participants' responses from the control group and the experimental group in Table 5.3. Participant EF01 from the experimental group responded:

> *"Friction is the thing that causes movements,"*

in the pre-test, but one cannot assume the participant has a conceptual understanding as the participant did not provide an example or explain what she meant, the learner should have used the word *enables* instead of *causes*.

Learners have intuitive ideas about scientific concepts that stem from their everyday experiences, (Lemmer, 2018). If the gap between these intuitive ideas and the correct scientific conception widens or is not refined towards the correct scientific concepts, learners will have misconceptions and the experiential perceptions will persist. The common experiential perception about friction is that it only hinders motion, while misconceptions include that it causes electricity since it is associated with heat or energy in electric circuits, and also that friction is a reaction or even an object (Liu & Fang, 2016). Three participants (CM04, MM07, CM05) from the control group and two participants (MM01, MM06) from the experimental group responded that friction is helpful to make objects in motion stop or slow down. Liu and Fang (2016) consider that this experiential perception of friction is associated with real-world experiences of the learners, and it is common among school teachers and university students as well.

Other learners assume friction is only present when a surface is rough or that a real-life smooth surface has no friction. In the national curriculum, a smooth surface is understood to be a surface without friction. The researcher considered this to be a challenge as it raises questions as to whether the learner will be able to apply friction in real life, as there is no perfectly smooth surface without friction. This was seen in one participant's (CM03) response:

"Friction is helpful when the surface is smooth and a problem when its hard"

The researcher noted participant CM03's response as a problem with vocabulary, as the participant saw that friction is an entity that is helpful when the surface is smooth and presented "hard" as the opposite of smooth. Liu and Fang (2016) posit that some misconceptions arise when a learner uses terms that don't have the same meanings in the context of science and their daily experiences. Such misconceptions are known as vernacular misunderstandings which surface due to a learner's insufficient reading skills, or unclear explanations from the textbooks used. The vernacular misunderstanding was also observed in one participant's (MM06) response as he used vague and undifferentiated language:

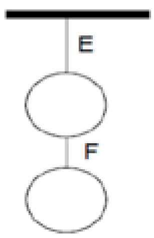
> *Friction is helpful when you want to stop a certain thing when it's in motion. And there is no force acting on it. Sometimes friction is a problem because it requires a certain amount of force to move an object depending on the friction, the greater the direction the more the force needed.* (MM06)

Another misconception identified was of learners thinking friction is an object or an entity, for instance, participant CM08's answer reveals that he thinks the friction resides inside the rope*:*

> *"Friction can attach to other friction which means friction can be applied to any rope".*

Item FT1

FT1 Two identical chandeliers are suspended from cable E attached to the ceiling and cable F attached between the chandeliers, as indicated in the diagram below.



Which ONE of the following relationships between the tension, TE, in cable E, and the tension, TF, in cable F is correct?

A	TE > TF
B	TE < TF
C	TE = TF ≠ 0 N
D	TE = TF = 0 N

When and why is tension different in the same string at two different points?

Figure 5.5: Item FT1 in the pre-test

Item FT1 in the pre-test tested the participants' conceptual understanding of tension forces in a rope, which was addressed by Activity 4 in the robotics intervention and Problem 4 in the traditional extra classes' intervention. The responses of some of the participants are recorded in Table 5.4, and the misconceptions identified are discussed.

Table 5.4: Responses of participants to Item FT1 in the pre-test

ITEM FT1: When and why is tension different in the same string at two different points?			
Control Group		**Experimental Group**	
EM01	where you always find lift or elecators accros the wiring strings	MF01	because of the weight which the first TE will experience more heavy tension than the other
MM05	the tension is different when TE>TF and the reason is because TE is higher that TF	MM01	the tension at point TE is different because the weight of the second chandelier is pulling the first chandellier so it is increasing the tension at point TE
MM02	is because of their distance is not the same. So they differ with the distance between the strings	MM03	the tension differs when tension TE with a short length appears to carry more masses of the chandeliers than TF which carries low mass of the secons chandelier
CF02	when there are objects in those strings, tension is different. Tension is different because the object above will have tension . Weight and tension holding it to the other object. While the object below will only have 2 forces (weight and tension)	CM02	the tension is different between TE and TF. Because TE is caring TF and TF pulls TE down. TE is pulled by the ceiling and TF
EM02	these two tension will pull with the same amount of force because the are in a series connection	EM03	because some of the two chandeliers will not be the same including tensions of E and F TE is the one that is greater than
CM04	the tension can be applied at the same string at two different points but the force will be different at each point	CM03	because the first string takes tension for both/more objects
CF05	it depends on how you compress the string	MF03	when the tension is different in the same string at two different points because there is tension and the other object will be weighing the other
MM07	its because the tension in TE has a force that equals to the object, and in TF the force is only equals to one object	MM06	the string experiences a bigger force at point E than F
CM05	when they are not connected in a linear	MF04	it is a different tension because of chandeliers at a same string are at two different points and they not have same or equal amount
MM08	it depends on the force applied to an object attached to the string	CF06	tension F is hanging on E, so E has too much tension that F
EF06	when the ceiling is down the cable goes up and the string will remain the same	CF07	when they have different mass the tension will be different in the same string because it will effect the two objects
CM07	because string F carries the weight of string E where else string F is hanging Freely	EF05	because the tension TE it is the one that helps TF or it is the one that is attached to the ceiling
CF03	I don't know	EM05	it is only different when the two chandellier are connected together
CM01	I don't Know	EM06	between TE and TF the one that is greater that the other is TE as it uplifts two chandeliers ad TF moves one chandelier
		CF08	its just that they don't work in the same way. They work differently
		CF09	when the strings are not on the same spot because the chandeliers are not on the same spot
		EF07	tension is different in the same string at two different points because the other point is attached to the ceiling while the other one is not
		CM08	because the tension can moved to another place. Which means tension can applaied to the same direction
		MM04	no clue

The qualitative section of Item FT1 was poorly answered, and the researcher noted that it could be that the participants misunderstood the question. The initial item (multiple choice) of FT1 referred to TE and TF, being the tensions in two separate strings, therefore the participants might have thought the open-ended item still referred to TE and TF as part of the question. The researcher noted this might have caused confusion in the learners, and thus they kept referring to TE and TF in their answers. Furthermore, the CAPS Technical Sciences policy documents do not explicitly state the use of massless ropes, however, the researcher considered that Technical Sciences should equip learners for articulation in the world of work and thus realistically one should understand the effect of tension in ropes that have mass. For ropes that have mass, different sections of the rope will pull a different mass. When an object is suspended on a rope with mass, force is exerted on both the mass of the object and all of the rope between the object and the end of the rope at the point furthest from the object. None of the participants showed a sound understanding of the concept in their answers.

Flores-Garcian et al. (2010) identified categories of tension misconceptions such as association with the proximity to an object, and association of tension with string length which was identified in some of the participants' responses in this study. These tension difficulties were identified in the pre-test results of participants from both the control group and the experimental group as shown in Table 5.4.

In the control group, Participant MM02 may have based his reasoning on the proximity of the chandeliers to each other or the lengths of the strings:

> "*Is because of their distance is not the same. So, they differ with the distance between the strings*."

At the same time, participant MM05 may have based his reasoning on the chandelier's proximity to the ceiling:

> "*The tension is different when TE>TF and the reason is because TE is higher that TF*".

In the experimental group, the tension misconception of proximity was identified in a few participants' (MF03, CF06, CF09, EF05, EF07) responses, for example, participant EF07 responded:

> *"Tension is different in the same string at two different points because the other point is attached to the ceiling while the other one is not."*

Other explanations also suggested the belief that the closer the chandelier is to the ceiling, the greater the tension force. Similar difficulties with the argument relating to proximity were observed in the responses of students in a study conducted by Flores-Garcia et al. (2010). The proximity misconception shows that the learners believe the ceiling (or the point of reference in similar studies) is the "source of the force", and at points far away from the ceiling, the force diminishes.

5.4 KNOWLEDGE OF PARTICIPANTS AFTER THE INTERVENTION

In this section, the researcher presents an overview of the results and responses from the participants in the post-test. The researcher deemed such analysis necessary to understand whether students' conceptions had changed after the robotics intervention. The discussion will start with the knowledge of the mentioned concepts, followed by a discussion of the identified misconceptions.

Item N2M1

N2M1 A **constant** net force, F, is applied to a crate which moves along a frictionless horizontal surface. Which ONE of the following quantities remains constant while force F acts on the crate?

A	the rate of change of velocity
B	the momentum
C	the work done on the crate
D	the kinetic energy

Do you think there will be a time when the crate will stop? If not, how would you slow down the crate or stop the crate in motion? Explain your answer.

Figure 5.6: Item N2M1 of the test instrument

In the post-test, Item N2M1 tested whether the participants' conceptual understanding of acceleration and net force had changed. The robotics intervention activity meant to address these concepts was Activity 1, and Problem 1 in the traditional extra class intervention. The post-test results in Item N2M1 are recorded in Table 5.5.

Table 5.5: Responses of participants to Item N2M1 in the post-test

ITEM N2M1: Do you think there will be a time when the crate will stop? If not, how would you slow down the crate or stop the crate in motion? Explain your answer				
Control Group			**Experimental Group**	
MM05	No, the crate will stop if friction is applied		MM04	yes, apply an external force that is opposite in direct
CM05	No, because there's no frictional force to slow down the moving crate while the net force is constant.		MF03	No, another force to the opposite direction must be added, in order for the crate to slow down
CM07	the crate won't stop unless a force of equal magnitude is applied in the opposite direction		MM06	no, if you apply an unbalanced force on an object which will be opposing the motion of the crate the crate will stop
MM02	no, the should be an unbalanced force that will act on the crate		CF07	another force have to come in contact with the create, opposite direction and have equal magnitude
CF02	No there won't be; By applying a non-zero force to the crate opposite it because that will decrease force at which the crate is moving		MF01	yes the will be a time the crate will stop in motion by increasing the load of the crate to be contact to the surface whereby the friction will be required to stop the object.
CF04	Yes, because of the frictional force that will be applied on the surface		CM02	No, the crate will not stop. Because the crate is moving along a frictionless horizontal surface. So it can't stop unless the is a rough surface
MM08	it will slow down or stop when there is a friction		EM06	No, make the surface an inclined plane because if the surface is inclined there will be friction acting against the crate or the steepness of the plane will decrease the movement of the plane
EF04	Yes, it will be stopped by the friction		CF09	no, by applying frictional force to the horizontal surface, we can stop the motion of the crate
MF02	It will stop because there is no friction		CF01	yes. The time it crate or shop momentum will move along a frictionless horizontal surface
CM01	to stop the crate you need to lift the crate then the crate will stop moving		MM01	yes, I will stop it by increasing the mass of the crate by putting something in because the acceleration is inversely proportional to the mass
EF03	Yes, if we stop applying force to the crate it will stop but not immediately		MM03	no, for the crate to stop, resistive force must be applied on an object so that the speed on an object can decrease from its constant
EM02	I would put less or small load inside the crate so that it will move slow until it stops. And it must move with a certain velocity until it stops		EM03	if the balance act upon it
CM04	No, remove the force applied		CM03	By applying more force
CF05	yes		MF04	yes. There will be a time when the crate will stop because a net force is in constant velocity and the work done on the crate
MM07	yes		EF01	Yes, kinetic energy because it might not move faster
CM06	There is a force acts on the crate and is constant without a direction		CF06	yes, because the work done on the crate will still remain constant
MF05	yes because the quantity will remain constant while the force is acting on the crate		EF07	yes, because there is applied force and the crate won't move at a constant speed
			EF05	no, I'll have to add the mass or I'll have to reduce the force.
			EM05	yes. As the applied force on the crate act the friction force also act upon the crate but in a constant speed and the net force will move at the same motion
			CF08	yes because the crate will stop because it goes on a frictionless surface

There was an improvement in the response rate for the correct concept in the experimental group as compared to the control group. Three (3) participants from the control group and four (4) participants from the experimental group answered correctly. Participant MM02 from the control group performed better in this item as compared to the pre-test by answering:

"no, the should be an unbalanced force that will act on the crate",

whereas in the pre-test he responded

"Yes. Because of will be using a stopwatch to count the time when the crate stops".

However, he should have added "in a direction opposite to the motion" for the statement to be correct. As seen in their responses, participants MF03 and MM04 from the experimental group showed an improvement in responding to the item which tested their ability to apply the knowledge that Newton's Laws do not exist in isolation from one another.

The post-test results showed that both the control group and the experimental group still had persistent misconceptions concerning forces acting on an object. Three participants (CM05, MM05, CF04) from the control group and two participants (MF01, MM03) from the experimental group had the same misconception in the pre-test and post-test. The participants identified friction as a force that could stop the crate in motion and their responses were the same before and after the intervention. This shows that for the five participants mentioned (CM05, MM05, CF04 and MF01, MM03), neither intervention was effective for Item N2M1. The participants gave mostly incomplete explanations and reasoning in responding to the open-ended question.

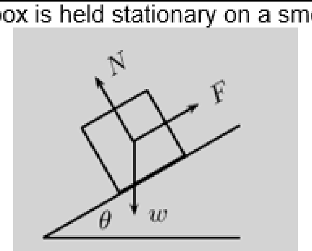
Participant CM04 revealed the common misconception that force is required for motion. The misconception was the same before and after the intervention: "No, remove the force applied", which shows the traditional intervention of extra classes was not effective for Item N2M1 for participant CM04.

Participant EF05 and MM01 still held the same misconception, adding more mass to increase the force, therefore one can conclude that the robotics intervention did not change this participants' perception.

The other participants showed a total misunderstanding for this item, and their responses after the intervention showed no improvement. These participants included participant CM06 from the control group and participants CF06, MM01, and CM08 from the experimental group. Thus, neither the traditional extra classes nor the robotics intervention was effective in remedying the misconceptions held by 38% of the participants in the control group and 43% of the participants in the experimental group concerning Item N2M1.

Item FGN1

FGN1 A box is held stationary on a smooth plane that is inclined at angle θ to the horizontal



F is the force exerted by a rope on the box, w is the weight of the box and N is the normal force of the plane on the box. Which of the following statements is correct?

A	$\tan\theta = \frac{F}{w}$
B	$\tan\theta = \frac{F}{N}$
C	$\cos\theta = \frac{F}{w}$
D	$\sin\theta = \frac{N}{w}$

Why do you think the box remains stationary?

Figure 5.7: Item FGN1 in the test instrument

In the post-test, Item FGN1 tested the participants' conceptual understanding of forces on an incline. The robotics intervention activity meant to address these concepts was Activity 2, and Problem 2 in the traditional extra class intervention. The post-test results in Item FGN1 are recorded in Table 5.6.

Table 5.6: Responses of participants to Item FGN1 in the post-test

ITEM FGN1: Why do you think the box remains stationary?			
Control Group		**Experimental Group**	
MM02	because the system is at equillibrium	MM04	there is no unbalanced force acting on it
CF02	the forces are in equillibrium. F = Fg parallel, N = Fg perpendicular	MF03	Because the forces are balance
CF04	because it is held stationary on the smooth plane and as long as the is no unbalanced force acting upon it, it will remain stationary	CF09	the forces acting on it are in equillibrium
EF03	because there is no force applied to the box	CM02	Because force is not applied on it. The must be a force so that the box can move. So it will not move unless the force is applied on it
CM06	the weight is over the force and normal force is cos theta	EF05	because the is no applied force
MF05	because the box is a normal force and F is the force exerted by a rope	EM05	the angle of theta zero so the box is at a constant speed that means it will not move and the is no frictional force applied
MM08	because there are no forces acting on the box	CF01	because the stationary is always at zero
EM02	because it if you add the right angle which is 90 degrees, everything will be zero, that means its constant	MF01	no the box is inclined by the slope so it accelerate it won't remain stationary. They will be some forces acting on the box like friction it will cause it to move from one place to other
CM01	the box won't stay stationary because the plane is smooth so the box will fall	MM01	because of the force exerted by the rope
CM05	because it is held at a point of theta and that makes it to remain stationary	MM03	because there are two equal forces acting horizontal to the inclined plane and in the same opposite direction

MF02	It remains stationary because they is no friction	EM03	because of the weight of the box and it is on a smooth plane
MM05	because there is no friction	CM03	the force is constant
CM04	no, force is applied on the box and it's stationary on a frictionless surface	EF07	the box remains stationary because there is no friction and its force is zero
CF05	because is not pulled and the statement says that the box is held stationary on the smooth plane	EM06	the box remains stationary because all the forces acting on the box are equal. The magnitude of the friction is equal to the force applied
		MM06	because the applied force has the opposing force which they are equal in magnitude
		MF04	because tan theta = F divided by N and force and newton according to me is the same thing
		EF01	the normal force isn't moving
		CF06	because it is inclined at angle theta to the horizontal
		CF07	the box will rain stationary because all the forces have equal magnitude. The forces are relative to the surface. The forces exerted are the same
		CF08	I don't understand anything here

From the control group, three (3) of the participants understood and answered the question correctly. It was evident that even before the pre-test, they had a correct perception of what it means for forces to be in equilibrium. For participant CF07\, one can identify the language and the framing of her answers to be a challenge, as evident in her answer:

> *"the box will remain stationary because all the forces have equal magnitude. The forces are relative to the surface. The forces exerted are the same*".

She has some understanding that certain forces are equal and that their direction ("relative to the surface") needs to be considered.

Inclusion of Newton's first law can be seen in participant MM04's answer:

> "*there is no unbalanced force acting on it*",

which shows that the participant understands that for the box to move from rest the forces should be unbalanced.

The post-test revealed that some participants such as MM08 and EF03 from the control group, and CM02 and EF05 in the experimental group, still had the misconception that if anything is stationary it has no forces acting on it. Participants CM04, MM05 and MF02 in the control group and participant EF07 in the experimental group held the smooth surface or frictionless surface accountable for the lack of movement, which shows they have no conceptual understanding of the principles involved.

In response to the question of why the box remains stationary on an inclined surface, two participants accounted for the stationary box by alluding to the forces being at equilibrium, in other words, that both the parallel and perpendicular components were balanced. Although the response rate was less on this question (eight participants left the test blank), the learners that did respond held either friction or the lack of friction accountable for the box remaining stationary. Most of the participants in both groups failed to express the correct reason why the box remained stationary. A few participants could account for either the horizontal or vertical forces being in balance but excluded other forces to account for the net force.

Item FF2

FF2 A long rope is attached to a crate. A dog pulling at the other end of the rope manages to move the crate across a flat surface of ice. The friction between the ice and the crate can be ignored. Read the following statements about the force applied by the dog on the rope and the motion of the crate.

1. If the dog applies a constant force, the crate will maintain a constant speed.
2. If the dog releases the rope when the crate is on the move, the crate will maintain a constant speed.
3. If the rope breaks the crate will move slower and stop.
4. If the rope breaks the crate will stop immediately.

Which of statements(s) above is/are true?

A	Only 3 is true
B	Only 2 is true
C	Only 1 and 2 are true
D	Only 1 and 3 are true
E	Only 1 and 4 are true

When is friction helpful? When is friction a problem?

Figure 5.8: Item FF2 on the test instrument

In the post-test, Item FF2 tested whether the participants' conceptual understanding of the implication of frictionless surfaces and the application of friction had changed. The robotics intervention activity that addressed these concepts was Activity 3, and Problem 3 in the traditional extra class intervention. The post-test results in Item FF2 are recorded in Table 5.7.

Table 5.7: Responses of participants to Item FF2 in the post-test

ITEM FF2: When is friction helpful? When is friction a problem?				
Control Group				**Experimental Group**
MM02	in cars, it helps cars break and stop and also friction gives us the ability to walk, if there wasn't friction we would not be able to walk. (friction between the ground and our shoes/feet). It is a problem on a machine, the machine will be worn out if not lubricated		EM05	if the dog release the rope when the crate is on the move then the crate will maintain a constant speed that's where the friction helpful is. If the rope breaks the crate will stop immediately
CF05	friction is a problem when you have an heavy load. Friction is helpful when the object is on speed or moving fast it will stop immediately because of friction		MF01	friction helps to generate heat. Friction enable a car to break. Friction enable a person to run fast. Friction disadvantage by generate heat by running on the rainy days with storms and the lightning strike on the charged surface on the ground
CF02	it is helpful in making objects to stop. When it doesn't allow motion		MM04	helpful when we need to slow down a moving object. Problem - when we need to move an object
CM04	friction is a problem when we have to pull loads across concrete floors or gravel roads but it is helpful when we use the brakes of the car to avoid an accident		EM06	friction is helpful when the crate has to stop because if there is friction present the crate will stop. Friction is a problem when the box has to be moved because the dog has to apply more force than the one of fthe friction for the crate to move
CF04	friction is helpful when you you want to stop an moving object. It a problem when you are pushing something on a rough surface		MM01	friction is helpful when an object is accelerating and need to stop. Friction is problem when pulling or pushing an object and friction can make you apply more force

EF04	it's helpful when an object is moving and needs to stop
MM08	friction is helpful when you want something to stop or slow down. Friction is a problem when you are drilling or making a templete
CM01	the friction is helpful when the is friction and Tension but it is a problem when the is no friction
MF05	friction is helpful when object moves and it's a problem when the object stops
CM05	friction is helpful in terms of being in a speed as it slowers the speed down. Friction is a problem when trying to accelerate with something that needs to accelerate on a smooth surface
EM02	the crate will move slower until its stops when the dog applies a constant force
MM05	friction is helpful if and only the

EF05	friction is helpful if ever you're using a machine lets say maybe the nail of the machine it takes out a hole so if ever there's no friction you can be hurt. A friction is a problem when ever a car is on speed so it won't be able to stop immediately
CF06	friction is helpful if the dog applies a constant force, the crate will maintain a constant speed. Friction is a problem if the rope breaks, the carte will move slower and stop
CF07	friction is needed is helpful when something needs to be slowed down or reduce the net force or acceleration. Friction is a problem when determining the acceleration and time
MF04	if the dog releases the rope when the crate is on the move, the crate will maintain a constant speed
MM03	friction is helpful when it is needed to stop an object at a needed time. It is a problem when an objects net force and acceleration is required to increase, or even when the time needs to be deduced
CM02	friction is helpful because it can help you to stop the crate when you slow down. Friction is a problem because it can make the rope to break when you are pulling the crate
CM03	when the surface is smooth. When the surface is rough
EF07	the friction is helpful when the crate moves slowly
MF03	on a frictionless surface, an interruption occurs
MM06	sometimes things are supposed to be stopped after a particular time and when we have friction we can determine that. They are other thing which we can apply a force on and those things will stop without a use of applying any opposing force on them
EM03	this friction is hepful when the rope breaks because it will stop the crate. A frictional is the problem when the dog applies a constant force
EF01	when you need to stop you won't be able to but sometimes friction might be helpful if you need to move something at a constant speed
CF01	when it across surfaces with applied force and the motion of the crate
CF08	a friction is helpful when it comes when you push something with an speed and thought that thing will hit something then the friction will stop that. A friction is not helpful when you push something with a speed and you found out that there is a rough surface and that thing will just stop
CF09	friction can be helpful in a situation like an occurring car crash. Friction from the brakes stops the car safely. Friction can be a problem

As can be seen in many of the participants' responses from the control group and the experimental group in Table 5.7, the participants understood friction as a force that opposes motion but only participant MM02 revealed an understanding that in many situations friction is required to enable motion, such as walking which requires "friction between the ground and our shoes/feet".

In the pre-test participant EF01 from the experimental group responded: *"Friction is the thing that causes movements"*, and in the post-test her response was: "*when you need to stop you won't be able to but sometimes friction might be helpful if you need to move something at a constant speed".* This response shows a change in conceptual understanding of Item FF2, but she still did not understand that friction enables a person to walk or a car to drive over a surface. She sees friction as the force that can balance an applied force so that an object can move at a constant velocity.

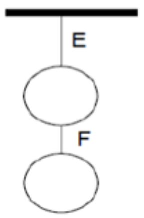
Participant MM04 from the experimental group also showed an improvement in conceptual understanding for Item FF2. In the pre-test, the participant responded: “no clue”, when asked about the usefulness of friction. In the post-test, participant MM04 responded that friction is “helpful when we need to slow down a moving object” and that friction is a “*problem - when we need to move an object*”. The response in the post-test shows improved conceptual understanding, but it also shows a partial understanding that friction is only helpful to stop or slow down a moving object.

Table 5.7 shows that the participants did not consider other possibilities about the usefulness of friction and the responses show that there was not much improvement for this item. It was evident that participants’ incorrect perceptions persisted after both interventions for three participants from the control group, and six participants from the experimental group.

Only participant CM05 from the control group and participant CM08 from the experimental group initially had a total misunderstanding of the concept of friction in the pre-test, while the post-test responses showed that they had a better understanding on the concept, but a limited experiential perception about the usefulness of friction. The responses were the same for participant CM04 of the control group, and participants MM01 and CM03, which showed that neither Problem 3 in the traditional intervention or Activity 3 in the robotics intervention were effective for scaffolding the experiential perceptions, to correct scientific reasoning for the participants in Item FF2.

Item FT1

FT1 Two identical chandeliers are suspended from cable **E** attached to the ceiling and cable **F** attached between the chandeliers, as indicated in the diagram below.



Which ONE of the following relationships between the tension, TE, in cable **E**, and the tension, TF, in cable **F** is correct?

A	TE > TF
B	TE < TF
C	TE = TF ≠ 0 N
D	TE = TF = 0 N

When and why is tension different in the same string at two different points?

Figure 5.9: Item FT1 in the test instrument

In the post-test, Item FT1 tested whether the participants' conceptual understanding of the force of tension in a string had changed. The robotics intervention activity meant to address these concepts was Activity 4, and Problem 4 in the traditional extra class intervention. None of the participants could answer the question on tension accurately; therefore, the researcher only identified the responses revealing misconceptions, which are identified in Table 5.8.

Table 5.8: Responses of participants to Item FT1 in the post-test

ITEM FT1: When and why is tension different in the same string at two different points?				
Control Group			**Experimental Group**	
MM08	the tension is different in the same string because of the mass		MF01	the more we increase the tension on the rope the more the stress or strain force increases because in the first point the tension was lower up until been acted other load on a cable it became higher going downwards and the gravity became unbalanced
CF04	when they are parallel to each other. When they are not parallel the tension is equal		MF03	when the other tension loads another because the bottom chandelier has more mass than the one hanging
MM02	Tension is different because of the forces that act on the objects, when the objects are hanging tension is different		MM03	it is different where tension E seemed to carry more mass than tension f as it take a big part in the to total tension of the string including constant normal and gravitational force
CF02	at E tension is equal to Fg plus tension in T. At F tension is equal to Fg only		CM02	if the E is not equal to F the tension will be different because they will not be carrying the same force or weight
EM02	Point TE in cable E it has the same mass with cable F		EM03	TE < TF and because of these two points are on the same object which can cause TF to fall
CM04	Tension is different in the same string when a force is applied on another force		CM03	tension is different when two objects are connected on the same string, different weight of objects
MM05	when the TE > TF tension will be different		MM04	when the objects are on the same rope and attached from a ceiling, TE holds the two objects and TF holds the last object
CM06	they don't share the points		CF09	when an external force is applied to the chandelier
MF05	when the chandeliers are suspended from the tension		MM06	the tension at E we consider to object unlike at F we look at one object
CF05	the string is different in the two point because the first point is closer to the string and the other one is distanced from the string		MF04	tension is different in the same string at two different points because of loads or force and two identical chandeliers are suspended
CM05	at strings E's end a force of tension is caried and that same point there starts string F with its weight and that were string E carrys two forces and string F carries only its weight		EM06	this is because the tension from cable E is of the chandelier and the ceiling, and the tension on cable F is now the tension of the ceiling and the first chandellier (Chandelier E).
			EF01	they are not moving at the same speed because they are two points
			CF06	cable E is attached to the ceiling while cable F attached between the chandeliers
			CF07	the objects masses affect the string which is attached between the chandeliers and use the force exerted to the objects
			EF05	the tension is different where TF is attached to TE and we can see that TE is attached to the ceiling and TF has gravity
			EM05	when TE>TF that mean TE is small then TE AND TE=TF not equal to 0N because the is force and acting on those object
			MM01	because the weight of the second chandeliers make the first cable E to have more tension that cable F
			CF08	because the tension attached between the chandeliers as calculated
			EF07	the tension is different when the two strings are separated and they are equal to zero
			CF01	Don't understand

In the post-test response for Item FT1, some learners still had the misconception that the tension in a rope is equal to the mass of the hanging object (for example EM02 from the control group and MM03 from the experimental group), and some learners thought that the closer the object was to the ceiling, the less tension it had. It should be stated that some of the learners could perhaps never have considered that ropes have mass and what the effect of that would be.

The misconception of proximity was still persistent in the responses of participants (CF06, EF05 and EM06) from the experimental group. The same results were observed in a study by Flores-Garcia et al. (2010), where students believed the ceiling (or the point of reference in similar studies) is the "source of the force", and at points far away from the ceiling, the force diminished.

5.5 TRIANGULATION OF RESULTS: PRE AND POST-INTERVENTION

The quantitative results from the multiple-choice questions were further enriched by the qualitative open-ended questions. The researcher used methodological triangulation to be able to answer the research questions. Fusch et al. (2018) described methodological triangulation as a way of combining data from different research methods to validate the results of a study. The researcher agrees with literature according to Jick (1979) who posits that the qualitative and quantitative methods should be viewed as complementary.

The chosen methodology is the ideal application for triangulation as it considers the best of both qualitative and quantitative methods to compensate for any deficiencies or flaws in either method, mitigates against bias and enhances the richness and depth of the data (Fusch et al., 2018; Jick, 1979). Figure 5.10 describes the process of methodological triangulation used for this study which aided the interpretation of the results.

To determine the effectiveness of the robotics intervention in more detail, the researcher analysed and compared the results from the pre-test and post-test of both groups for the open-ended items. There was a narrow focus on the open-ended items to determine participants' reasoning when they answered correctly in the multiple-choice items. Zhou et al. (2016) posit that participants are afforded more time to deliberate and write about their understanding of concepts through open-ended tests. Teachers and researchers can thus observe potential misconceptions and how learners tackle such misconceptions and therefore gain insight as to why some learners have difficulty understanding particular concepts (Zhou et al., 2016). The next subsections aim to triangulate the quantitative items with their qualitative responses. Participants' pre- and post-test responses were analysed as the researcher inferentially interpreted the responses in terms of conceptual understanding for each item.

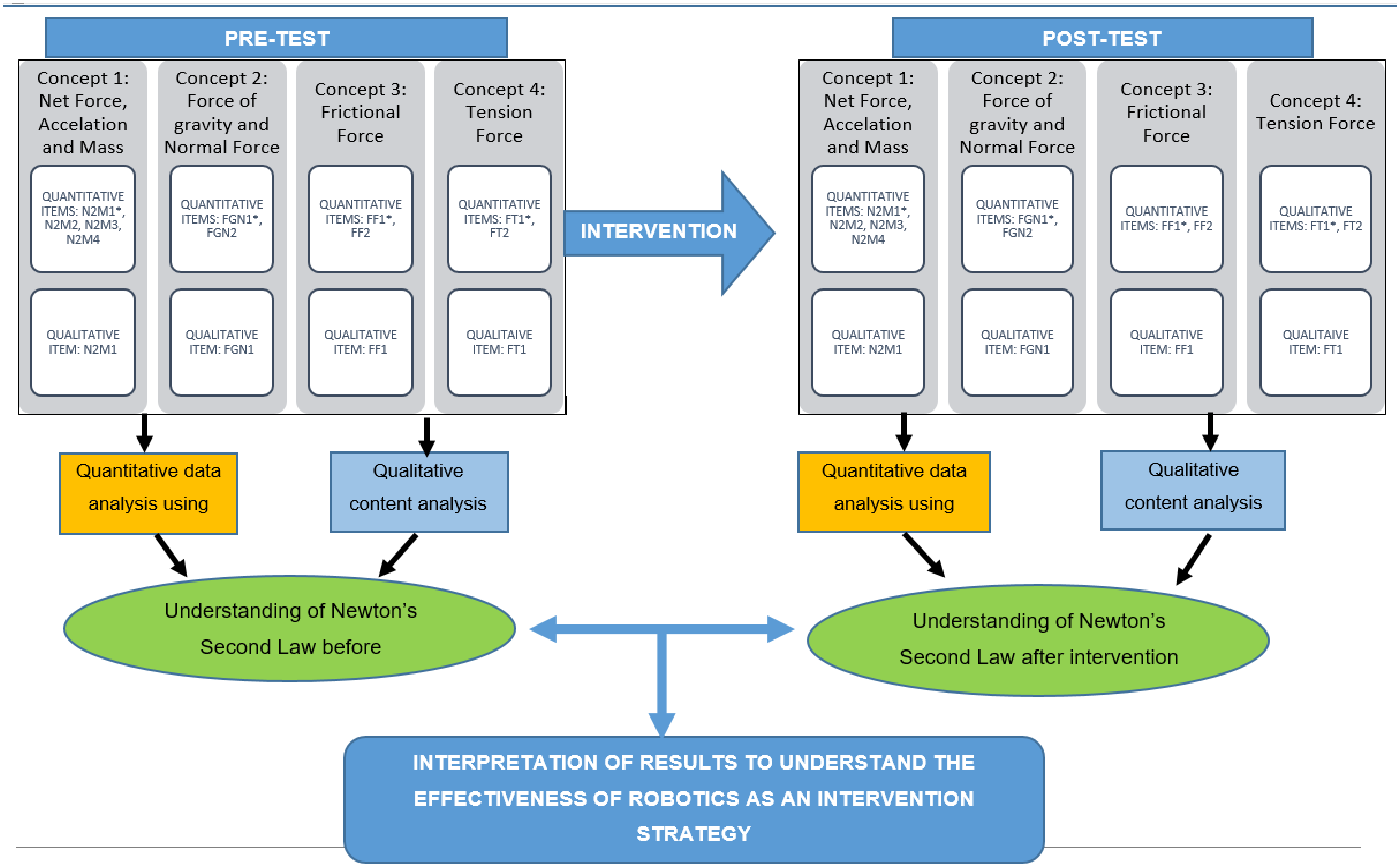


Figure 5.10: Illustration of the triangulation of results process

In the following sections, the discussions include an analysis of the responses for each participant in instances where a participant gave the correct response in the multiple-choice question, but a wrong explanation or answer in the open-ended questions.

ii. Item N2M1 (comparison of pre-test and post-test)

N2M1 A **constant** net force, F, is applied to a crate which moves along a frictionless horizontal surface. Which ONE of the following quantities remains constant while force F acts on the crate?

A	the rate of change of velocity
B	the momentum
C	the work done on the crate
D	the kinetic energy

Do you think there will be a time when the crate will stop? If not, how would you slow down the crate or stop the crate in motion? Explain your answer.

Figure 5.11: Item N2M1 in the test instrument

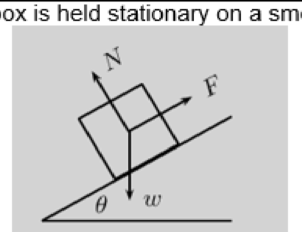
Table 5.9: Comparison of pre-test and post-test conceptual reasoning for Item N2M1

	Participant	Pre-test	Post-test	Pre-test reasoning	Post-test reasoning
Experimental Group	**CM03**	D	A	by applying a force that is big than the inertia of an object	By applying more force
	EF01	C	A	I don't know	Yes, kinetic energy because it might not move faster
	EF05	D	A	no, I'll have to increase the mass of the object	no, I'll have to add the mass or I'll have to reduce the force.
	EM05	C	A	yes because it will reach the point where the crate is constant	yes. As the applied force on the crate act the friction force also act upon the crate but in a constant speed and the net force will move at the same motion
Control Group	**CF05**	A	A	yes the crate will stop	yes
	MF05	B	A	The crate will continue while it remains constant. If the crate breaks by slowing it down the crate will stop moving	yes because the quantity will remain constant while the force is acting on the crate

In the post-test, six participants from the control group, and nine participants from the experimental group answered the multiple-choice item correctly. However, upon inspection of the responses, the researcher observed that some participants answered correctly in the multiple-choice item, but gave the incorrect response to the open-ended question. In Table 5.9, all the participants listed (except for participant CF05 in the pre-test), answered incorrectly in the multiple-choice section of the pre-test but improved and answered correctly in the multiple-choice section of the post-test. However, the researcher noted that although the multiple-choice answers were correct, the participants did not have the correct conceptual understanding as revealed in their responses. Participants EF01 and EF05 from the experimental group had no conceptual understanding as their responses and the language used showed that they did not understand the question. Participant CF05 answered correctly in the multiple-choice questions, however, the answer was not substantiated as she only answered “yes”. Duit and Treagust (2003) defined the notion of conceptual change with the purpose of scaffolding students’ pre-existing ideas towards the correct science concepts, which occurs at many different levels. There is no evidence in these participants’ responses from the post-test in Item N2M1, that an extensive refinement and rearrangement of existing cognitive schemas occurred as compared to their responses in the pre-test.

iii. Item FGN1 (comparison of pre-test and post-test)

FGN1 A box is held stationary on a smooth plane that is inclined at angle θ to the horizontal



F is the force exerted by a rope on the box, w is the weight of the box and N is the normal force of the plane on the box. Which of the following statements is correct?

A	$\tan\theta = \frac{F}{w}$
B	$\tan\theta = \frac{F}{N}$
C	$\cos\theta = \frac{F}{w}$
D	$\sin\theta = \frac{N}{w}$

Why do you think the box remains stationary?

Figure 5.12: Item FGN1 in the test instrument

Table 5.10: Comparison of pre-test and post-test conceptual reasoning for Item FGN1

	Participant	Pre-test	Post-test	Pre-test reasoning	Post-test reasoning
Experimental group	**EM05**	D	B	N/A	the angle of theta zero so the box is at a constant speed that means it will not move and the is no frictional force applied
	EM02	A	B	the box will move slowly until it reaches zero and it will remain constant	because it if you add the right angle which is 90 degrees, everything will be zero, that means its constant
Control group	**MM08**	C	B	because there is nothing moving the box or there is no force applied	Because there are no forces acting on the box

Table 5.10 displays the comparative results of Item FGN1, which tested participants' knowledge of the normal force and gravitational force. One participant from the experimental group, and two participants from the control group, initially answered incorrectly in the pre-test but answered correctly in the post-test but with wrong conceptual reasoning.

Participant EM05 initially did not provide a reason in the pre-test, and in the post-test, his response revealed that he did not understand why the box remained stationary on the inclined plane, as he made reference to constant speed and immediately afterwards stated that the block will not move and there was no frictional force applied. The two participants from the control group, EM02 and MM08, also did not reveal any conceptual understanding in their responses. For Item FGN1, the conceptual change did not occur for one participant from the experimental group, and two participants from the control group. It is evident that for the three participants in Table 5.10, conceptual development was not successful.

iv. Item FF2 (comparison of pre-test and post-test)

FF2 A long rope is attached to a crate. A dog pulling at the other end of the rope manages to move the crate across a flat surface of ice. The friction between the ice and the crate can be ignored. Read the following statements about the force applied by the dog on the rope and the motion of the crate.

1. If the dog applies a constant force, the crate will maintain a constant speed.
2. If the dog releases the rope when the crate is on the move, the crate will maintain a constant speed.
3. If the rope breaks the crate will move slower and stop.
4. If the rope breaks the crate will stop immediately.

Which of statements(s) above is/are true?

A	Only 3 is true
B	Only 2 is true
C	Only 1 and 2 are true
D	Only 1 and 3 are true
E	Only 1 and 4 are true

When is friction helpful? When is friction a problem?

Figure 5.13: Item FF2 in the test instrument

Table 5.11: Comparison of pre-test and post-test conceptual reasoning for Item FF2

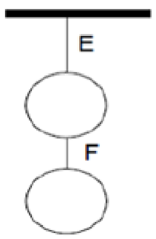
Experimental group	**MM06**	A	B	friction is helpful when you want to stop a certain thing when it's in motion. And there is no force acting on it. Sometimes friction is a problem because it requires a certain amount of force to move an object depending on the friction, the greater the direction the more the force needed	sometimes things are supposed to be stopped after a particular time and when we have friction we can determine that. They are other thing which we can apply a force on and those things will stop without a use of applying any opposing force on them

Control group	**CF02**	C	B	friction is helpful in tar roads, making cars to be able to turn and stop. Friction is a problem when driving it finishes off your tyres	it is helpful in making objects to stop. When it doesn't allow motion

Item FF2 obliged learners to choose the correct statement from the provided options and required learners to predict what would happen in the given scenario. Only two participants (one from the experimental group, and one from the control group) answered correctly for the multiple-choice question in the post-test but provided the wrong reasoning for the open-ended question. In the pre-test, participant MM06 responded that “the greater the direction the more force needed”, which is incorrect, but since the rest of the statement makes sense, one may assume that the learners meant “friction” instead of “direction”. In the post-test, participant MM06’s response was not well articulated which may point towards poor conceptual understanding. Thus, the conceptual change did not occur. Participant CF02’s response was not entirely wrong; the response was correct in the pre-test. Therefore, participant CF02’s response reveals that there was no conceptual change, because, in the post-test, her response reverted and was not articulated to show that she understands the usefulness of friction beyond just “making objects stop”.

v. Item FT1 (comparison of pre-test and post-test)

FT1 Two identical chandeliers are suspended from cable **E** attached to the ceiling and cable **F** attached between the chandeliers, as indicated in the diagram below.



Which ONE of the following relationships between the tension, TE, in cable **E**, and the tension, TF, in cable **F** is correct?

A	TE > TF
B	TE < TF
C	TE = TF ≠ 0 N
D	TE = TF = 0 N

When and why is tension different in the same string at two different points?

Figure 5.14: Item FT1 in the test instrument

Table 5.12: Comparison of the pre-test and post-test conceptual reasoning for Item FT1

		Pre-test	Post-test	Pre-test reasoning	Post-test reasoning
Experimental Group	**MM03**	A	A	the tension differs when tension TE with a short length appears to carry more masses of the chandeliers than TF which carries low mass of the second chandelier	it is different where tension E seemed to carry more mass than tension f as it take a big part in the to total tension of the string including constant normal and gravitational force
	CM03	A	A	because the first string takes tension for both/more objects	tension is different when two objects are connected on the same string, different weight of objects
	MM04	A	A	no clue	when the objects are on the same rope and attached from a ceiling, TE holds the two objects and TF holds the last object
	MM06	A	A	the string experiences a bigger force at point E than F	the tension at E we consider to object unlike at F we look at one object
	MF04	A	A	it is a different tension because of chandeliers at a same string are at two different points and they not have same or equal amount	tension is different in the same string at two different points because of loads or force and two identical chandeliers are suspended
	EF01	A	A		they are not moving at the same speed because they are two points
	CF07	C	A	when they have different mass the tension will be different in the same string because it will affect the two objects	the objects masses affect the string which is attached between the chandeliers and use the force exerted to the objects
	EF05	A	A	because the tension TE it is the one that helps TF or it is the one that is attached to the ceiling	the tension is different where TF is attached to TE and we can see that TE is attached to the ceiling and TF has gravity
	CF08	D	A	it's just that they don't work in the same way. They work differently	because the tension attached between the chandeliers as calculated
Control Group	**MM02**	B	A	is because of their distance is not the same. So they differ with the distance between the strings	Tension is different because of the forces that act on the objects, when the objects are hanging tension is different
	CF02	A	A	when there are objects in those strings, tension is different. Tension is different because the object above will have tension . Weight and tension holding it to the other object. While the object below will only have 2 forces (weight and tension)	at E tension is equal to Fg plus tension in T. At F tension is equal to Fg only
	CM04	A	A	the tension can be applied at the same string at two different points but the force will be different at each point	Tension is different in the same string when a force is applied on another force
	CF05	A	A	it depends on how you compress the string	the string is different in the two point because the first point is closer to the string and the other one is distanced from the string
	MF05	B	A		when the chandeliers are suspended from the tension

In general, the responses from participants in Item FT1 of the test-instrument reveal that the participants who took part in this study have a poor level of conceptual understanding of the force of tension, in particular, the force of tension in strings that have mass. The multiple-choice section for this item was well answered, but the open-ended section reflected a poor level of perceptual understanding of the force of tension in strings that have mass. .

The poor responses from the participants may be attributed to the item construct, in that it was not related to the multiple-choice questions. Seven (7) participants from the experimental group and three (3) participants from the control group chose the correct answer in the pre-test and post-test, but the responses in the open-ended questions were not correct. It is evident that due to the phrasing of the open-ended question, the responses revealed that there was no refinement and rearrangement of the existing cognitive schemas, as conjectured by (Lemmer, 2018), to guide understanding of the force of tension in strings with mass. It may also be argued that the Technical Sciences CAPS curriculum does not specify that the force of tension in strings with mass must be taught, and it is thus up to the teachers' discretion to include it in the classroom.

5.6 CONCLUSION

In this chapter, the researcher discussed the qualitative data analysis procedure that was undertaken to understand the effect of the robotics intervention. The baseline knowledge was discussed with attention paid to initial conceptual understanding of Newton's second law, as well as the responses from the participants revealing misconceptions. The knowledge of the participants after the intervention was also analysed in the same way, and comparisons were further made of the participants' responses before the intervention and compared to their responses after the intervention. The results included responses from open-ended questions that required participants to describe their understanding of acceleration, net force, frictional force, gravitational force and the force of tension.

The findings in this study indicate that the conceptual understanding of the participants as revealed in the responses to open-ended questions improved for a small number of participants after the robotics intervention. In comparison, there was an improvement in the results of the control group as well. Although the participants in the experimental group improved in the phrasing and construction of their responses, the researcher accepts that the responses of the open-ended questions do not give conclusive evidence of an improvement in conceptual understanding.

In the next chapter, the researcher will discuss the implications of the results of this study against existing literature, and the research questions that guided the study.

6 CHAPTER SIX: DISCUSSION AND CONCLUSION

6.1 INTRODUCTION

The previous chapters outlined the purpose of the study which was to find out the effect of robotics as an intervention strategy in Technical Sciences. The findings of the study were presented and included the quantitative results in Chapter 4 and the qualitative results in Chapter 5.

In this chapter, the researcher will discuss the findings under the research questions, the limitations, and the scientific merit of the study. The contribution of the research study to science teaching will be presented in the concluding section of this dissertation, and recommendations for future research will be made.

The findings will be discussed and linked to the relevant literature under the following sub-questions:

1. What is the baseline knowledge of Newton's second law of Grade 12 Technical Sciences learners?
2. What is the knowledge of Newton's second law of the control group and experimental group after the intervention?
3. What is the difference between the outcomes of an assessment about Newton's second law of the experimental group and the control group after the intervention?

Finally, the triangulation of results will be discussed to summarise the sub-questions on whether robotics as an intervention strategy has an observable effect on learners' knowledge of Newton's second law.

6.2 DISCUSSION OF THE RESEARCH QUESTIONS

6.2.1 Research Sub-question 1: Baseline knowledge of the participants before the robotics intervention

The first sub-question of this research study was: "What is the baseline knowledge of Newton's second law of Grade 12 Technical Sciences learners?". The baseline test showed that most of the participants had some prior knowledge regarding Newton's Second law of motion.

The quantitative results showed that before the intervention, the mean test score for the experimental group was M = 3.67, and the mean test score for the control group was M = 3.57. This score was below the median score of five (5)which showed that overall participants from both groups scored below the expected average. The researcher inferred that participants from the control group understood how to calculate the net force given the variables of frictional force and constant acceleration because item N2M4 had the most correct responses from the control group. For the experimental group, Item FT1 was the most correctly answered and required the participants to compare tension in two cables. The pre-test quantitative results further revealed that both the experimental group and the control group struggled with the concept of frictional force, as Item FF2 was intended to test. Item FF2 received the lowest responses with only three (3) participants from the control group and two (2) participants from the experimental group answering Item FF2 correctly. These quantitative results were juxtaposed with the open-ended responses in Chapter 5.

Open-ended questions can reveal more than the multiple-choice items, which concurs with a study done by Tuder and Urban-Woldron (2013). The study by Tuder and Urban-Woldron (2013) aimed to explore student's beliefs about Newtonian mechanics and used additional interviews to understand whether new information would be obtained with open-ended questions. The results of their study revealed that conceptual understanding could not be assessed by exclusively analysing single FCI items, because some learners guessed the answers from the pre-test, while some had misconceptions, and some did not understand the questions at all, while others read the questions inaccurately. In the current study, the pre-test consisted of four open-ended questions to see whether the results of the multiple-choice questions could be understood further. The qualitative results, which were the responses of the participants, showed that although participants had some knowledge of the critical aspects of Newton's second law, they also had more misconceptions. The initial question tested the participants' ability to recognise that the Newtonian laws do not exist in isolation, and only four (4) participants (two from the control group and two from the experimental group) could make the connection that Newton's second law follows from the first law. Atasoy et al. (2011) investigated the use of worksheets to remedy science teachers' misconceptions of force and motion. In their literature, reference was made to studies that indicated misconceptions that students held. Some of the senior high school students in their study indicated that force is required to maintain motion, and this was found to be one of the most difficult misconceptions to remedy. Consistent with the literature, the pre-test qualitative results of this study found that a few learners believed that an object in motion has a continuous force acting on it, and the object will eventually stop if the object is removed.

The second open-ended item tested the participants' conceptual understanding of forces on an incline, force components and the concept of equilibrium. The quantitative section for this item was poorly answered, with only four (4) participants in the experimental group and three (3) participants in the control group answering correctly. Further analysis of the conceptual reasoning of the participants in the qualitative results showed that learners understood equilibrium forces only to some degree, while eight (8) participants in total did not attempt to answer the qualitative section of this Item. From the 34 participants who attempted to answer the open-ended question, the majority of participants from both groups did not understand that forces on an incline have parallel and perpendicular components. The misconception identified in the responses was that a stationary object has no forces acting on it. Research conducted by Liu and Fang (2016) identified the same misconception in learners and accounted the incompetence to contextualise Newton's laws in different situations as a limiting factor for the learners to be able to apply the same laws out of the classroom and in new situations.

The third open-ended item, Item FF2, probed participants' understanding of the usefulness of friction. The majority of participants stated strongly that friction is helpful to hinder motion or slow down objects when required, and friction is a problem if it makes motion difficult. The researcher supposes that Technical Sciences is a subject intended to allow learners to apply physics conceptual knowledge to real-life situations, and therefore it is not always the case that friction is a problem only when it hinders motion. This supposition is reinforced by research conducted by Liu and Fang (2016), who believed that the participants were not entirely wrong when they stated their intuitive perceptions but most learners' misconceptions will persist when they are not encouraged to explore terms that don't have the same meanings in their daily life experiences and the science context (Lemmer, 2018).

The CAPS Technical Sciences policy documents do not explicitly state the use of massless ropes, however, the researcher considered that Technical Sciences should equip learners for articulation in the world of work and thus realistically one should understand the effect of tension in ropes that have mass, which was the aim of open-ended Item FT1. Item FT1 had the most correct responses from the experimental group in the quantitative results, and an average performance from the control group in the pre-test. The qualitative results, however, indicated low performance and poor conceptual understanding was detected for tension being different at different points in the same string. Furthermore, the qualitative analysis for this item showed that learners had misconceptions about tension in strings generally. The majority of the participants viewed tension to be the greatest in the string of an object being closest to the ceiling (in the case of two hanging objects, one below the other). These findings are congruent with research studies by Flores-Garcia et al. (2010), who identified categories of tension misconceptions such as association with the proximity to an object, and association of tension with string length. These difficulties with tension were identified in the pre-test results of participants from both the control group and the experimental group in this research study.

In summary, the baseline test showed that the quantitative results of both groups were similar, as the mean difference was *MD* = 0.1. The performance of both groups was average, and the qualitative results further justified the requirement for some kind of intervention for the concepts of Newton's second law of motion. The open-ended responses of the participants were unpacked and analysed, and misconceptions were identified from both the control group and the experimental group before the robotics intervention.

6.2.2 Research Sub-question 2: Knowledge after robotics intervention

The second sub-question of this research study was: "What is the knowledge of Newton's second law of the control group and experimental group after the intervention? To answer the second research sub-questions, the researcher consulted the quantitative results in Section 4.3 of Chapter 4, and the qualitative results in Section 5.3 of Chapter 5. The post-test results showed that there was an improvement in most of the participants' responses regarding general concepts of Newton's second law as well as the concept of frictional force.

In the post-test, the mean test score of the learners from the control group stayed the same, while the experimental group results improved by a mean difference MD = 1.15. The quantitative results showed that there was an improvement in the test scores for the experimental group after the robotics intervention, while the traditional intervention was not effective as there was a decrease in the mean of the test results from the control group. In the control group, Item N2M4 was still the most correctly answered item, which showed that perhaps the concepts of calculating the net force given the variables of frictional force and constant acceleration were further reinforced and strengthened.

For the experimental group, Item N2M2 had the most correct responses. This item required the participants to determine the effect of a decreasing net force on acceleration and velocity. The intervention activity aimed to address this concept was robotics Activity 1, and Task 1 from the traditional intervention class, that focused on calculating the acceleration and net force of the system. Liu and Fang (2016) investigated some common misconceptions held by physics and engineering mechanics education students about force and acceleration. The study revealed that acceleration misconceptions are much harder to correct since acceleration is a more abstract concept than force. Furthermore, learners often think speed and acceleration mean the same and they use the terms interchangeably (Hestenes et al., 1992). Most learners may associate velocity and force as being proportional when they cannot distinguish between velocity and acceleration as descriptors of motion.

However, the results also indicate that neither the traditional extra classes nor the robotics intervention were effective in remedying the misconceptions held by 38% of the participants in the control group and 43% of the participants in the experimental group for Item N2M1. There was no significant improvement for the participants' responses to Item FF2, regarding the use of friction, which shows that neither interventions were effective for scaffolding the experiential perceptions, to correct scientific reasoning for the participants in Item FF2.

Therefore it was concluded that knowledge of Newton's second law of motion improved regarding the concepts of acceleration and net force, but the intervention was not effective in improving conceptual understanding for the concepts of frictional force and force of tension.

6.2.3 Research Sub-question 3: Difference between the control group and the experimental group after the robotics intervention

The third sub-question of this research study was: "What is the difference between the outcomes of an assessment about Newton's second law of the experimental group and the control group after the intervention?" To ascertain the effectiveness of the robotics intervention, the statistical parameters, and comparison is made in the performance of participants for each item.

Statistically, the mean of the control group stayed the same (M=3.19), thus the mean difference (MD=0) is indicative that the normal traditional extra classes were not effective in improving the quantitative test scores. On the other hand, the mean difference of the experimental group (MD=1.15) showed there was an improvement after the robotics intervention. An independent sample t-test performed using SPSS software showed that the difference in post-test scores between the control group (n = 21, *M* = 3.19, *SD* = 1.16) and the experimental group (n = 21, *M* = 4.57, *SD* = 1.43) was statistically significant, $t(40) = 3.42$, $p = 0.001$. The Sig. (2-Tailed) value in the results was $p = 0.001$, which is less than 0.05. A *p-value* of less than 0.05 indicates that there is a significant difference between the two groups. Therefore, we can conclude that there is a statistically significant difference between the mean of the test scores between the control group and the experimental group. The *Null hypothesis one (H01),* that was stated in Chapter 1 is therefore rejected as there is a significant difference in the test results of learners who participate in the robotics intervention program to those who do not participate in the robotics.

An item comparison was made to determine the performance of all the participants in each item:

i. The item comparison for the pre-test and post-test showed that the items where participants from both groups did not improve were items FF2 and FT1. For FF2, the average item facility was found to be IF (FF2) = 0.12, which means this item was found to be very difficult for participants from both groups before and after the intervention. High ability learners failed to answer the item correctly contrary to the expectations. This showed that participants did not understand what follows from Newton's first law – a body will remain at rest, or continue in constant motion in a straight line unless acted upon by an external force. Item FT1 of the test instrument showed a decline in the performance of both groups. There was a decline of 4,7% in the performance of the control group and a decline of 28,5% in the performance of the experimental group. The item required learners to interpret the given information, draw a free body diagram and apply Newton's second law to arrive at the correct answer. The decline in performance for both groups for this item was concerning. The average item facility for this item was IF (FT1) = 0.51, which means it was just average – not too easy and not too difficult.

ii. The item with the most correct responses from the control group was item N2M4, with 13 correct responses after the intervention. The item could be classified as a cognitively lower-order item because participants were given the applied force (in the horizontal direction) and the frictional force, and were required to determine the net force acting on the system moving with constant acceleration. Understanding the implication of Newton's second law of motion and vector addition substantiates why Item N2M4 had the most correct responses for the control group.

iii. The item with the most correct responses was item N2M2 for the experimental group, with 17 correct responses after the intervention. Item N2M2 from the test instrument probed the participant's understanding of the relationship between net force and acceleration, and what this acceleration means in terms of velocity.

iv. The item where participants showed the most improvement was item N2M3 for the control group, and items N2M3 and FF1 for the experimental group. The researcher classified item FF1 as an item of middle-order cognitive demand. Participants first had to interpret the given information from keywords in the problem statement, and understand that constant velocity means the acceleration is zero. The item had an average item facility of 0.31, which showed moderate difficulty.

6.2.4 Answering the main research question: The effect of robotics as an intervention strategy in Technical Sciences

Considering the analysis of results and discussions, as well as the comparison between the participants who took part in the robotics intervention, to those who did not, triangulating the results assisted the researcher to understand that robotics as an intervention strategy in a Technical Sciences class has an effect to some extent. There was a significant improvement in motion-related concepts where learners were exposed to the concepts practically and tangibly. The study also revealed that there was no change in the test-items probing the concepts of friction and the force of tension in ropes that have mass, therefore the intervention was not effective for those theoretical concepts.

Similar findings regarding learners' conceptual understanding, were reported by Setyani et al. (2016) in a study that aimed to describe the conceptual ability of students based on Newton's laws of motion. Students were required to represent Newton's laws of motion verbally and visually. The results showed that students had the incorrect concept about the effect of constant force and constant acceleration while velocity increases. The students related the constant velocity with uniform linear motion. The verbal representation (interview responses of the students) showed that the students assumed that an object has no velocity when there is no net force. Students were able to state the equation of Newton's second law, however, they had difficulty in applying the equation to solve problems. Setyani et al. (2016) emphasised that concept comprehension at a deeper level needs to take place as it affects students' ability of problem-solving in physics. The results of this study are consistent with these results from the literature.

6.3 LIMITATIONS OF THE STUDY

There were several benefits of this research study, nevertheless, the researcher understands that the present study had some limitations. Firstly, a small sample was selected, the data gathering process was based on one school site and selecting learners enrolled for Technical Sciences, and therefore the study cannot be assumed to provide findings that are generalisable to all learners who enrol for Technical Sciences. The study only focused on Newton's Second Law topics that are in the prescribed national curriculum, presented in 2018. As the curriculum was still in its inception year, several changes were made to the curriculum along the course of the study. Furthermore, the time spent at the site chosen was limited, considering the existing barriers and lack of resources of the said school.

The instrument for data collection had a limited number of questions, with ten (10) items being multiple-choice, and four open-ended questions. The test instrument used focused on a wide range of questions to test the participants' conceptual understanding, however, the robotics activities were limited to focus on motion problems. Therefore, there was a disjoint between what learners were experientially learning, and what was tested in the cases of those questions that required theoretical unpacking. It is the researcher's view that the test instrument may be improved by adding items that assess different dimensions of the participants' understanding concerning Newton's second law.

In analysing the responses from the open-ended questions, the researcher understood that there were items on the research instrument that were not motion-related problems, but problems of a theoretical nature. Liu and Fang (2016) identified "thinking-oriented" and "doing-oriented" methods on how to correct student misconceptions on force and acceleration. The robotics intervention was a hands-on constructionist approach, henceforth conceptual change strategies and conceptual change interventions as identified by Liu and Fang (2016) are needed to improve the research instrument.

The researcher also identified the language barrier of the participants in fully answering the questions, and noted this as vernacular misconceptions that are associated with learners' insufficient reading skills or textbooks used. Technical Sciences was first examined in Grade 12 in 2018, therefore there is not a variety of textbooks or reading material to bridge the reading skills deficiency gap. The researcher suggests improving the participants' reading skills by also improving the quality of the Technical Sciences textbooks as proposed by Liu and Fang (2016).

The researcher also identified limitations in the content breadth and content depth of Technical Sciences, as the level of cognitive demand in the topic of Newton's second law in Technical Sciences was not equivalent to the level of cognitive demand in the items of the test instrument. however, the findings will provide information concerning how the Department of Basic Education can strengthen the content depth pertaining to the Mechanics section of Newton's Second Law.

6.4 SIGNIFICANCE OF THE RESEARCH AND CONTRIBUTIONS OF THE PRESENT STUDY TO RESEARCH

The Minister of Basic Education recently announced that the robotics and coding curriculum was in the final stages of review, and a pilot would be implemented in 2020 at selected schools in South Africa. Considering the dearth of literature regarding robotics education in South African Schools, this research study will be able to contribute to the current discourse of 21^{st}-century learning and the effect of new technologies in the classroom. The timing of this research study is pivotal as teachers, parents, education specialist and researchers would need to understand similar studies and the contribution of robotics in South African classrooms.

A specific intervention has been mentioned in this study, which, by leaning toward a cognitive refinement instructional approach, is catering for a common ground where complementary characteristics for constructionism and robotics learning will blossom into substantive learning experiences for both teacher and student.

In terms of the study's educational consequences, teachers will have access to documentation on the theme of robotics and education, as well as a basis for intervention in Technical Sciences, based on the research conducted. This research paves the way for new lines of work for both teachers and learners in the STEM field, given its relevance to the science community in general and learners' understanding of Newton's Second Law of Motion in particular.

Using a conceptual refinement approach, underpinned by constructivism and constructionism, the study adds to the body of knowledge on teaching Newton's Second Law in Technical Sciences. Furthermore, the findings of the study have functional implications for program and curriculum developers, robotics instructional leaders, and STEM teachers, as they will use the findings to create curricula and classroom experiences that emphasize a wider range of procedural and conceptual skills.

6.5 RECOMMENDATIONS

The purpose of this study was to understand the effect of using robotics as an intervention strategy in Technical Sciences in a Grade 12 class. The researcher wanted to understand whether the learners who participated in the study would have an improved understanding of Newton's Second Law concepts. Findings of the current study suggested that although there was an improvement in the quantitative results, the robotics intervention activities of merely three weeks were insufficient to induce a significant conceptual change in the participants.

These findings hold important implications for future research and therefore the following topics are recommended for further research:

- Conduct a longitudinal study on the current Senior Phase cohort (Grade 7 to Grade 9 learners) who would offer the robotics curriculum and study the effect on learning outcomes and learning achievement in the Further Education and Training phase.
- Conduct a study on pedagogical approaches such as project-based learning to teaching digital skills and robotics in the Further Education and Training Phase (Grade 10 to Grade 12).

- Conduct a study on understanding how experience in the robotics activities contribute to qualitive shifts in understanding Newton's Second Law concepts, and investigate to what extent robotics intervention contribute to addressing learner misconceptions.

The researcher also mentioned some challenges concerning Technical Sciences as a subject. To address some of the challenges mentioned in the first chapter of this study relating to the overall learner performance in the subject, the following suggestions can be explored:

- Intended curriculum: A curriculum mapping of Technical Sciences as a subject in South Africa is needed, according to the vision and framework of the "Three Stream Model" because Technical Sciences should not be a duplication of physical sciences. Guidelines should be put in place as to the level of cognitive demand for specific topics such as Newton's second law of motion.
- Implemented curriculum: The researcher noted that the language proficiency of the participants was low, as they were not English Home Language speakers. The researcher recommends that teachers take this into account when teaching scientific concepts in Technical Sciences.

To improve on the use of robotics as a learning and teaching support material, the following approaches can be explored:

- The use of project-based learning methods and interventions to incorporate robotics and for learners to display understanding in a range of other ways.
- Participation in robotics challenges such as the World Robot Olympiad (WRO) that offers learners an opportunity to participate in problem-solving competitions in a team with tournaments around the country and different parts of the world, (World Robot Olympiad Association, 2020).
- Participation in the FIRST® LEGO® League challenge that guides learners to learn STEM concepts and apply their skills in a competitive environment, (For Inspiration and Recognition of Science and Technology (FIRST) and the LEGO Group, 2020)

6.6 CONCLUDING REMARKS

In this chapter, the researcher presented the findings in relations to the main research question and sub-questions that informed the study. The researcher also presented the limitations and significance of the study and concluded by presenting recommendations for further research. This research study presented an opportunity for the researcher to understand that all learners are different and that knowledge should be presented to them in a manner that makes them realise the need to change their existing misconceptions, especially if their experiential knowledge causes the misconception.

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7 APPENDICES

7.1 APPENDIX A: DATA COLLECTION INSTRUMENTS

7.1.1 APPENDIX A1: TEST INSTRUMENT

Answer the following questions by placing an X in the most appropriate box. Answer fully in the spaces provided.

SECTION A: ACCELERATION, MASS AND NET FORCE (NEWTON'S SECOND LAW OF MOTION)

N2M1 A **constant** net force, F, is applied to a crate which moves along a frictionless horizontal surface.

Which ONE of the following quantities remains constant while force F acts on the crate?

A the rate of change of velocity

B the momentum

C the work done on the crate

D the kinetic energy

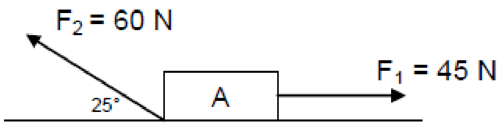
Do you think there will be a time when the crate will stop? If not, how would you slow down the crate or stop the crate in motion? Explain your answer.

N2M2 An object is moving to the right while a net force is acting on the object to the right. The net force decreases steadily but is not yet zero. Which row describes the effect this has on the magnitudes of the acceleration and the velocity of the object?

	Acceleration	Velocity
A	increases	increases
B	decreases	increases

C	remains the same	remains the same
D	remains the same	Increases

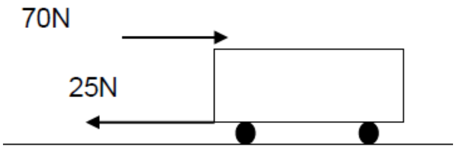
N2M3 Object A is at rest on a frictionless horizontal plane as indicated in the diagram below.



If the forces act on the object as shown in the diagram, the object will ...

A accelerate to the right.
B accelerate to the left.
C move at a constant velocity to the right.
D move at a constant velocity to the left.

N2M4 A woman pushes a trolley in a supermarket with a horizontal force of 70 N. During the motion, a frictional force of 25 N acts on the trolley. The trolley moves with a constant acceleration.

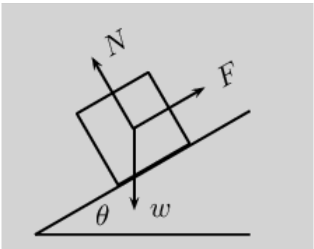


The net force acting on the system is:

A 45 N.
B 25 N.
C 70 N.
D 95 N.

SECTION B: FORCE OF GRAVITY AND NORMAL FORCE

FGN1 A box is held stationary on a smooth plane that is inclined at angle θ to the horizontal



F is the force exerted by a rope on the box, w is the weight of the box and N is the normal force of the plane on the box. Which of the following statements is correct?

A $\tan\theta = \frac{F}{w}$

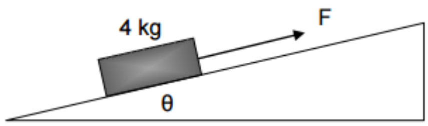
B $\tan\theta = \frac{F}{N}$

C $\cos\theta = \frac{F}{w}$

D $\sin\theta = \frac{N}{w}$

Why do you think the box remains stationary?

FGN2 A block with a mass of 4 kg is pulled upwards along a frictionless slope, inclined at an angle θ, with a force F, as shown in the sketch below.



Which ONE of the following equations can be used to calculate the magnitude of the normal force (N)?

A $N = (4)(9,8)\sin\theta$

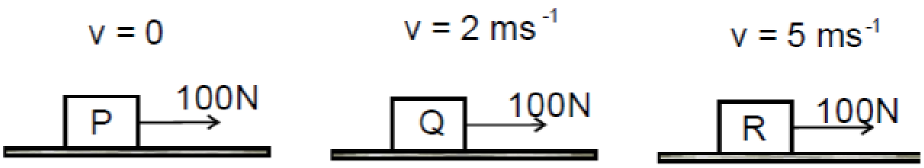
B $N = F - (4)(9,8)\cos\theta$

C $N = F + (4)(9,8)\cos\theta$

D $N = (4)(9,8)\cos\theta$

SECTION C: FRICTION

FF1 Three boxes are being pulled across surfaces with applied forces as indicated. Blocks that are in motion, move with constant velocity.



Rank the magnitudes of the **frictional forces** acting on the boxes :

A $F_P < F_Q < F_R$
B $F_P < F_Q = F_R$
C $F_P = F_Q = F_R$
D $F_P > F_Q > F_R$

FF2 A long rope is attached to a crate. A dog pulling at the other end of the rope manages to move the crate across a flat surface of ice. The friction between the ice and the crate can be ignored. Read the following statements about the force applied by the dog on the rope and the motion of the crate.

1. If the dog applies a constant force, the crate will maintain a constant speed.
2. If the dog releases the rope when the crate is on the move, the crate will maintain a constant speed.
3. If the rope breaks the crate will move slower and stop.
4. If the rope breaks the crate will stop immediately.

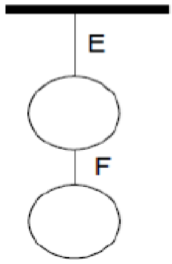
Which of statements(s) above is/are true?

A Only 3 is true
B Only 2 is true
C Only 1 and 2 are true
D Only 1 and 3 are true
E Only 1 and 4 are true

When is friction helpful? When is friction a problem?

SECTION D: TENSION

FT1 Two identical chandeliers are suspended from cable **E** attached to the ceiling and cable **F** attached between the chandeliers, as indicated in the diagram below.

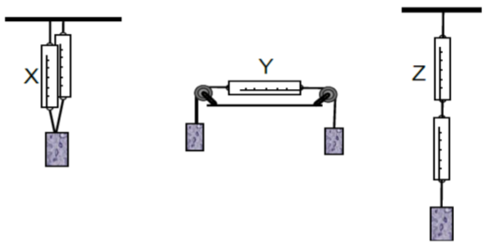


Which ONE of the following relationships between the tension, TE, in cable **E**, and the tension, TF, in cable **F** is correct?

A TE > TF
B TE < TF
C TE = TF ≠ 0 N
D TE = TF = 0 N

When and why is tension different in the same string at two different points?

FT2 The diagrams show identical blocks, each with mass 5,0 kg attached to identical scales. The scales are calibrated in newton. The masses of the scales are negligible. Which row correctly shows the readings on the scales marked X, Y and Z?



	X	**Y**	**Z**
A	24,5 N	49 N	49 N
B	49 N	24,5 N	24,5 N
C	24,5 N	0 N	49 N
D	24,5 N	98 N	49 N

Thank you for taking the time to complete this test. Should you have any questions, please feel free to contact:

Katlego Leshabane: 0711869369 or leshkat.lego@gmail.com

7.1.2 APPENDIX A2: ANSWERS TO MULTIPLE CHOICE ITEMS

SECTION A: ACCELERATION, MASS AND NET FORCE (NEWTON'S SECOND LAW OF MOTION)

N2M1	A
N2M2	B
N2M3	B
N2M4	A

SECTION B: FORCE OF GRAVITY AND NORMAL FORCE

FGN1	B
FGN2	D

SECTION C: FRICTION

FF1	C
FF2	B

SECTION D: TENSION

FT1	A
FT2	C

7.1.3 APPENDIX A3: EXPECTED ANSWERS TO OPEN-ENDED QUESTIONS

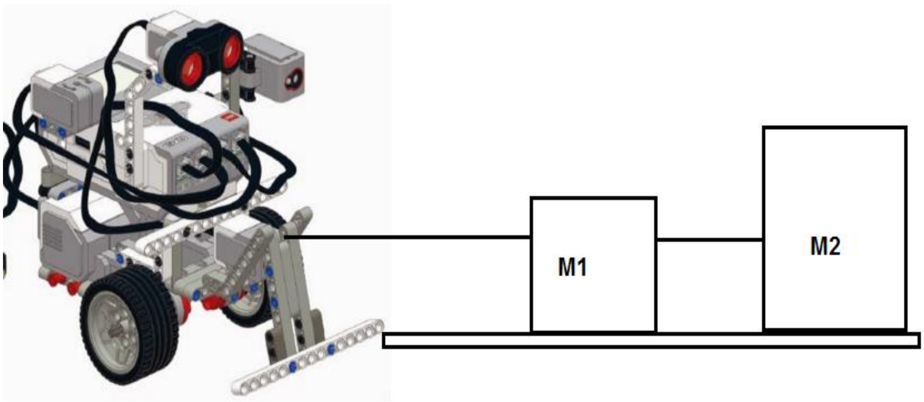
ITEM	Possible Response	Possible misconception or misperception that may be the learner's answer
N2M1 How would you slow down the crate or stop the crate in motion?? Explain your answer.	• Add an external/unbalanced force in the opposite direction	• Learners tend to associate force with the velocity instead of acceleration, so they may answer decrease the speed • Force is a property of an object. An object has a force and when it runs out of "force" it stops moving. • All objects eventually stop moving when the force is removed. The learner might answer – remove the force
FGN1 Why do you think the box remains stationary?	• Fnet=0 • Acceleration=0	• Weight and mass are the same thing. Proper Conception: Mass is a measure of the amount of matter that forms (or composes) an object. Weight is the result of the force of gravity on the mass of an object. • If anything is stationary it has no forces acting on it. An object that has balanced forces or no force acting on it must be stationary." • When a surface is smooth it means there is no friction • Gravity accelerates heavy objects more than light ones. So the box is not heavy
FF2 When is friction helpful? When is friction a problem?	• Frictional forces are sometimes useful as they may help objects move. Consider trying to walk if friction were not present For example, the tread of a tire is designed to maximize friction (traction) between the tire and the road and friction can be used to produce heat when needed.	• Friction always hinders motion. Thus, you always want to reduce or eliminate it. • Friction is the same thing as a reaction • Friction depends on the movement • Friction is associated with energy, especially heat • Friction causes electricity • Friction is thought of as an object
FT1	• When the rope has mass, then one section of the rope will be pulling more	• The tension in the rope must equal the weight of the hanging object.

When and why is tension different in the same string at two different points?	mass (it will be pulling some rope and also the object) than the section farther from the object. So, close to the object, the rope pulls and exerts a force on only the object and a small amount of rope. At the end of the rope (the furthest point from the object) the rope is exerting force on both the mass of the object and all of the rope between the object and the end of the rope.	

7.2 APPENDIX B: ACTIVITIES FROM ROBOTICS INTERVENTION

ACTIVITY 1

Mass, Acceleration and Net Force



- Connect the two blocks with a light inextensible string, and connect the system to your robot with a light inextensible string.
- Program your robot to move at a constant power of 75 for 1m
- Estimate the mass of each block and complete the table
- Record the time it takes for the robot to pull the two wooden blocks across 1m
- Calculate the acceleration using the formula: $\boldsymbol{a} = \frac{2\Delta x}{\Delta t^2}$
- Calculate the force applied on the system using newton's second Law

Table 1: Determine the Force Applied

Wooden Blocks		Total mass (m1+m2)	Displacement	Time	Acceleration	Force applied
M1	M2					
			1m			
			1m			
			1m			
			1m			
Average						

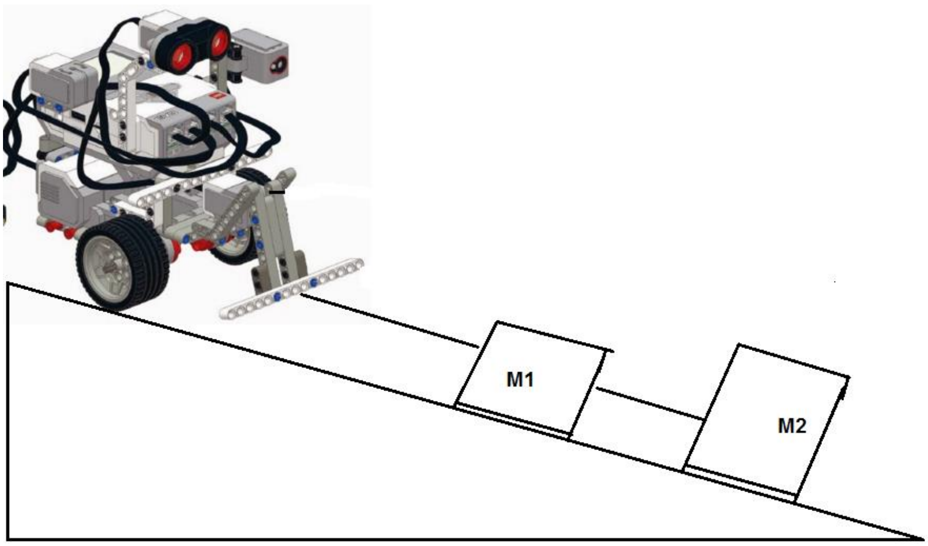
1. What was your understanding of the concept of force in this activity?

2. How did you determine the force applied?

3. How would you apply this kind of robotics activity in your Township?

ACTIVITY 2

Force of Gravity and Normal Force



- Build and program a robot with the ability to move a two-block system – Both on an inclined plane.
- Your robot must be built in such a way that it will be able to pull the two-body system at different angles (think power or passive attachments)
- Use your protractor to measure the angles from the horizontal
- Program your robot to move at a constant power of 75 for 1m
- Record the time it takes for the robot to pull the two wooden blocks across 1m
- Calculate the acceleration using the formula: $\boldsymbol{a} = \frac{2\Delta x}{\Delta t^2}$
- Calculate the force applied on the system
- The masses of the two blocks must not change for all five angles
- Specify which two masses you used on your answer sheet

Table 1: Determine the Kinetic friction

Angle	Displacement	Time	Acceleration	Force applied
	1m			
	1m			
	1m			
	1m			
	1m			

1. Calculate the magnitude of the:

1.1. Vertical component of the gravitational force when the angle is 30° to the horizontal

1.2. Normal force when the angle is 30° to the horizontal

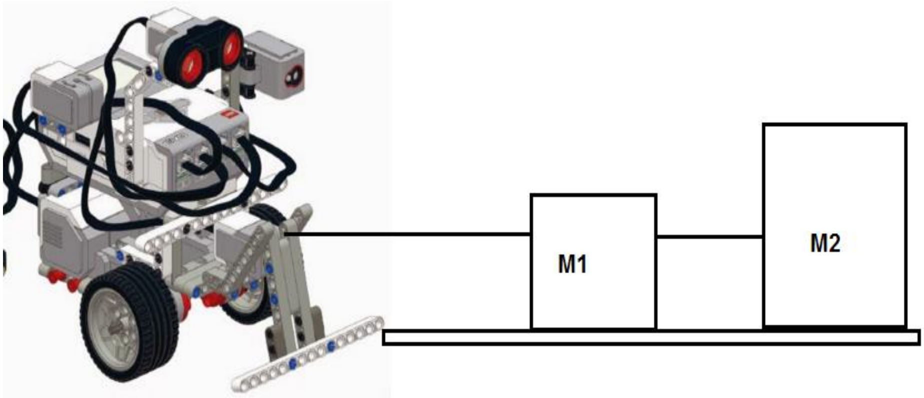
2. Calculate the magnitude of the tension in the string connecting the two blocks when the angle is 30° to the horizontal

EXTENDED QUESTION

How does the angle of the applied force affect the acceleration of the system? How does it affect the gravitational force?

ACTIVITY 3

Force of Friction



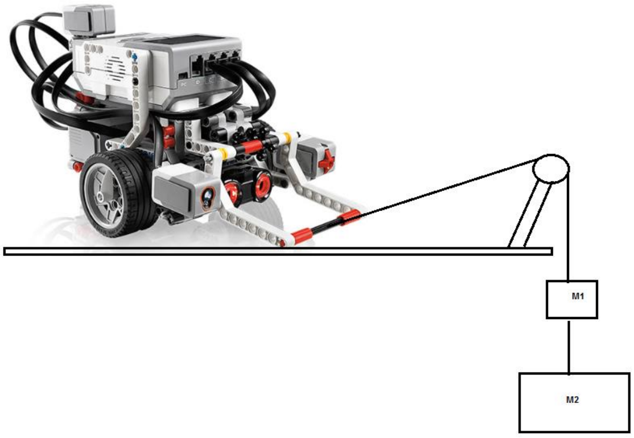
- Connect the two blocks with a light inextensible string, and connect the system to your robot with a light inextensible string.
- Program your robot to move at a constant power of 75 for 1m
- Record the time it takes for the robot to pull the two wooden blocks across 1m
- Hence, use Newton's second law of motion to determine the kinetic friction in terms of μ_k

1. Determine whether the surface area of the block or the type of surface affects friction

2. Did you consider the effect of friction when conducting activities using robotics? Explain why or why not.

ACTIVITY 4

Tension Force



- Build and program a robot with the ability to move a two-block system – Both hanging vertically on a frictionless pulley.
- Program your robot to move at a constant power of 75 for 1m
- Record the time it takes for the robot to pull the two wooden blocks across 1m
- Calculate the acceleration using the formula: $\boldsymbol{a} = \frac{2\Delta x}{\Delta t^2}$

Table 1: Determine the acceleration

Hanging mass		Δx	Δt	Δt^2	a
Block 1	Block 2				
		1m			
		1m			
		1m			

Questions

1. Discuss how your group carried out this activity to arrive at your answers.

2. What did you find difficult about this activity?

3. How would you apply the concepts you learned in this activity in your Township or surrounding? Do you think there is an issue or problem in your community that can be solved by this activity?

7.3 APPENDIX C: RELATIONSHIP BETWEEN ROBOTICS INTERVENTION, CONCEPTUAL FRAMEWORK AND TEST INSTRUMENT

Table C: Relationship between Robotics Intervention, conceptual framework and test

INTERVENTION	BIG IDEAS (What learners should know after completing the activity)	HOW THE CONCEPTUAL FRAMEWORK WILL BE APPLIED	TEST ITEMS
Activity 1 **Mass, Acceleration and Net Force**	**Free Body Diagrams** • A free body diagram is used to show all of the forces acting on an object. **The relationship between the Normal Force, weight and friction** • Gravity's effect on an object is called the force of weight. • The force of friction always opposes the motion of an object. **Constant force** • A constant force accelerates a given mass with constant acceleration **Constant Speed** • Acceleration is a measure of the change in velocity over time, therefore an object can accelerate while travelling at a constant speed but not at a constant velocity • Since velocity is the speed of an object in a given direction, at a constant speed (meaning no change in the magnitude of the velocity) an object could be	*Constructivism (use of artefacts for learning)* Learners will be facilitated through a robotics activity and encouraged to use the experience to create meaningful knowledge *Constructionism (building of artefacts for learning)* Build the Riley Rover Robot as indicated in the Lego Mindstorms instruction manual. Programming the Riley Robot to Move Straight Forward and Backward *CRIA* 1.Lego Mindstorms Robot - Practical activity of a robot moving across a distance 2.Attention directed to **constant speed → zero net force, constant acceleration→ constant force,** 3.Physics principles to be articulated: 4.Open end questions to encourage reflection	N2M1 N2M2 N2M3 N2M4

	changing its direction, and thus, accelerating as in rotational motion. **Zero Net Force** • The vector sum of all the different forces acting on an object in different directions will give the net force of an object. If these forces are equal in opposite directions, then the net force is zero		
Activity 2	**Free body diagrams** **Constant applied force** **Coefficient of friction** It is defined as the ratio of the force of **friction** to the normal force, μ = F / N. It is a value that shows the relationship between the force of **friction** between two objects and the normal reaction between the objects that are involved. **Net force and the two-block system** • When solving force problems, all of the forces acting on an object must be calculated. • When determining the net force acting on an object, the horizontal and vertical forces are calculated independently. **Constant velocity**	*Constructivism (use of artefacts for learning)* Learners will be facilitated through a robotics activity and encouraged to use the experience to create meaningful knowledge *Constructionism* Build a robot either using the instruction manual or from their thinking Connect two blocks with a light inextensible string, and connect the system to the robot with a light inextensible string *CRIA* 1. Lego Mindstorms Robot - Practical activity of a robot pulling a block system 2.Attention directed to **Solving simultaneous equations to determine the unknown variable**	KR2 CR1 CR2 AA3

	When the change in displacement over time remains the same. Constant velocity does **not** imply that v= $0 m.s^{-1}$ When velocity is constant then the acceleration of the object is equal to zero. **Simultaneous equations to determine unknown variables** • The net force is the sum of all forces acting on an object. • The force of friction always opposes the motion of an object.	3.Physics ideas to be discussed: Free body diagram, calculation of the coefficient of kinetic friction 4. Open-ended questions to encourage reflection: Determine whether the surface area of the block or the type of surface affects friction	
Activity 3	**Forces of two-block systems in the vertical and horizontal direction** Key Idea: Apply Newton's 2nd law to each mass separately. • When determining the net force acting on an object, the horizontal and vertical forces are calculated independently. • The net force is the sum of all forces acting on an object. **Normal force when pulling at an angle** The magnitude of the normal force when an object is being pulled vertically or at an angle depends on the net force and acceleration of the system **Tension**	*Constructivism (use of artefacts for learning)* Learners will be facilitated through a robotics activity and encouraged to use the experience to create meaningful knowledge *Constructionism* Build and program a robot with the ability to move a two-block system - One in a horizontal plane **with or without friction**, and a second hanging vertically from a string over a frictionless pulley *CRIA* 1. Lego Mindstorms Robot - Practical activity of a robot pulling a two-block system	KR1 AA2 AA4 SE1 SE2

	What about tension? **Force applied** **What about the applied force?**	2. Attention directed to **Normal force, Tension, Force Applied** 3. Physics principles to be articulated: **Resolving a vector (force) into its components** 4. Open-ended questions to encourage reflection: How does the angle of the applied force affect the acceleration of the system? How does it affect the normal force?	
Activity 4	**Tension and the Inclined Plane** • Tension is the internal force in a string rope or cable that supports an object. When analysing force on an inclined plane, the reference frame can be rotated so that the surface of the inclined plane is parallel to the x-axis. • When solving tension or incline plane problems, all of the forces acting on an object must be indicated. • When determining the net force acting on an object, the components perpendicular and parallel to the inclined plane are calculated independently. • The net force is the sum of all forces acting on an object. • The force of friction always opposes the motion of an object. **The normal force on the inclined plane**	*Constructivism (use of artefacts for learning)* Learners will be facilitated through a robotics activity and encouraged to use the experience to create meaningful knowledge *Constructionism* Build and program a robot with the ability to move a two-block system – Both on an inclined plane. The robot must be built in such a way that it will be able to pull the two-body system at different angles *CRIA*	AA1 AA5 CR3

	• The weight has a component mgsinθ parallel to the place; mg is the weight. • The normal force is always perpendicular to the surface of the plane	1.Lego Mindstorms Robot -Practical activity of a robot pulling a two-body system on an incline 2.Attention directed to **Parallel and perpendicular components of Gravitational force**, 3.Physics principles to be articulated: Solving equations simultaneously to find external forces 4. Open-ended questions to encourage reflection: How does the angle of the applied force affect the acceleration of the system? How does it affect the gravitational force?	
Activity 4 Force of Tension	**Tension and hanging mass on a pulley system** Apply Newton's second law to each object separately The objects have the same tension in different directions All forces must be calculated Treat the horizontal and vertical components independently	*Constructivism (use of artefacts for learning)* Learners will be facilitated through a robotics activity and encouraged to use the experience to create meaningful knowledge *Constructionism* Build and program a robot with the ability to move a two-block system – Both hanging vertically on a frictionless pulley.	FT1 FT2

		<u>CRIA</u> 1.Lego Mindstorms Robot - Practical activity of a robot pulling two masses vertically, connected by a light inextensible string 2. Attention directed to **Tension, Gravitational force, Constant force** 3. Physics principles to be articulated: Gravitational acceleration is independent of weight 4. Open-ended questions to encourage reflection: What will happen to the Tension in the string(s) if you increase the acceleration? Does the way the masses hang matter, i.e. can a larger mass pull up on a smaller mass? Explain.	

7.4 APPENDIX D: TRADITIONAL/CONVENTIONAL INTERVENTION ACTIVITIES

<u>Sources for control group activities</u>

2015 SEPTEMBER NORTHERN CAPE DBE Physical Sciences Paper 1

2016 SEPTEMBER NORTH WEST DBE Physical Sciences Paper 1

2015 FEBRUARY/MARCH DBE Physical Sciences Paper 1

2014 NOVEMBER DBE Physical Sciences Paper 1

Problem 1

Newtons Second Law of Motion Equation – Mass, acceleration and Net Force

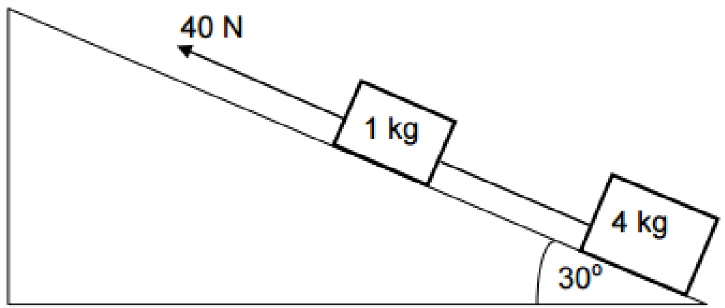
Test items: N2M1, N2M2, N2M3, N2M4

The picture below shows a boy pushing a lawn mower, of mass 22 kg, across a lawn at constant speed, applying a constant force at 35N.

1.1	Define *normal force* in words.	(2)

1.2	Draw a labelled free body diagram of the lawn mower to show all the forces acting on it.	(4)	
While the lawn mower is moving, the boy attempts to accelerate it by applying a force of 170 N. The coefficient of kinetic friction between the mower and lawn is 0,68.			
1.3	Calculate the magnitude of the kinetic frictional force between the lawn mower and the lawn.	(4)	
1.4	Perform a calculation to explain why the boy gets tired pushing on the lawn mower.	(3)	
		[**13**]	

Problem 2 **Force of Gravity and Normal Force**
Test items: FGN1 and FGN2
A block of mass 1 kg is connected to another block of mass 4 kg by a light inextensible string. The system is pulled up a rough plane inclined at 30o to the horizontal, by means of a constant 40 N force parallel to the plane as shown in the diagram below.



The magnitude of the kinetic frictional force between the surface and the 4 kg block is 10 N. The coefficient of kinetic friction between the 1 kg block and the surface is 0,29.

4.1	Draw a labelled free-body diagram showing ALL the forces acting on the 1 kg block as it moves up the incline.		(5)
Calculate the magnitude of the:			
4.2	4.2.1	Kinetic frictional force between the 1 kg block and the surface	(3)
	4.2.2	Tension in the string connecting the two blocks	(6)
			[14]

Problem 3

Frictional Force

Test Items: FF1 and FF2

Two wooden blocks of masses 2kg and 3kg respectively are placed on a rough horizontal surface. They are connected by a string. A constant horizontal force of 10N is applied to the second string attached to the 3kg mass as shown in the diagram below. Assume that both the strings are light and inextensible.

The system moves towards the right with a *constant velocity.*

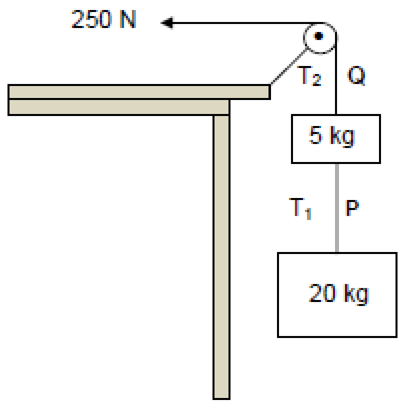
2.1.	Define the term kinetic frictional force	(2)
2.2.	What is the magnitude of the force acting on the system?	(1)
2.3.	Draw a labeled free-body diagram showing ALL the forces acting on the 3kg block as it moves to the right	(5)
2.4.	Calculate the coefficient of kinetic friction between the surface of the table and the two wooden blocks	(5)
The 10 N force is increased to 30 N so that the system now accelerates.		
2.5.	Calculate the acceleration of the system	(5)
		[17]

Problem 4

The Force of Tension

Test items: FT1 and FT2

Two blocks of masses 20 kg and 5 kg respectively are connected by a light inextensible string, P. A second light inextensible string, Q, attached to the 5 kg block, runs over a light frictionless pulley. A constant horizontal force of 250 N pulls the second string as shown in the diagram below. The magnitudes of the tensions in P and Q are T_1 and T_2 respectively. Ignore the effects of air friction.



5.1	State Newton's Second Law of Motion in words.	(2)
5.2	Draw a labelled free-body diagram indicating ALL the forces acting on the **5 kg block**.	(3)
5.3	Calculate the magnitude of the tension T_1 in string P.	(6)
5.4	When the 250 N force is replaced by a sharp pull on the string, one of the two strings break.	
	Which ONE of the two strings, **P** or **Q**, will break?	(1)
		[12]

7.5 APPENDIX E: CONSENT LETTERS

7.5.1. APPENDIX E1: LETTER TO OBTAIN CONSENT FROM THE SCHOOL

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Education

PRINCIPAL

"Understanding the effect of Robotics as an intervention strategy in a Technical Sciences class"

I,____, the principal of ____hereby voluntarily and willingly agree to allow my school to participate in the above-mentioned study introduced and explained to me by Katlego Leshabane, currently a student enrolled for a Masters degree at the University of Pretoria.

I further declare that I understand, as was explained to me by the researcher, the aim, scope, purpose, possible consequences and benefits, and methods of collecting information proposed by the researcher, as well as the means by which the researcher will attempt to ensure the confidentiality and integrity of the information she collects.

____________________________ _______________________

Full name Signature

____

Date

Official School Stamp

7.5.2. APPENDIX E2: LETTER TO OBTAIN CONSENT FROM THE PARENTS AND

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Education

LEARNERS

LETTER of CONSENT
PARENTAL CONSENT FOR LEARNER UNDER THE AGE OF 18

VOLUNTARY PARTICIPATION IN THE RESEARCH PROJECT ENTITLED
"Understanding the effect of Robotics as an intervention strategy in a Technical Sciences class"

I, ____, herby give permission for my child ___________________________________ to participate as an individual in the above-mentioned study introduced and explained to me by Katlego Leshabane, currently a student enrolled for a Masters degree at the University of Pretoria. I further declare that I understand, as was explained to me by the researcher, the aim, scope, purpose, possible consequences and benefits and methods of collecting information proposed by the researcher, as well as the means by which the researcher will attempt to ensure the confidentiality and integrity of the information she collects.

______________________ ______________________ ____________

Full name Signature Date

LETTER of ASSENT
INDIVIDUAL PARTICIPANT (under 18 years of age)

I, ____, hereby voluntarily and willingly agree to participate as an individual in the above-mentioned study introduced and explained to me by Katlego Leshabane, currently a student enrolled for a Masters degree at the University of Pretoria. I further declare that I understand, as was explained to me by the researcher, the aim, scope, purpose, possible consequences and benefits and methods of collecting information proposed by the researcher, as well as the means by which the researcher will attempt to ensure the confidentiality and integrity of the information she collects.

______________________ ______________________ ____________

Full name Signature Date