A STUDY OF WHY SOME PHYSICS CONCEPTS IN THE SOUTH AFRICAN PHYSICAL SCIENCES CURRICULUM ARE POORLY UNDERSTOOD IN ORDER TO DEVELOP A TARGETED ACTION-RESEARCH INTERVENTION FOR NEWTON'S SECOND LAW

A thesis submitted in fulfilment of the
requirements for the degree of

MASTER OF SCIENCE
of
RHODES UNIVERSITY

By
Kathleen Margaret Cobbing

ORCid: 0000-0002-3161-4502

December 2019

ABSTRACT

Globally, many students show a poor understanding of concepts in high school physics and lack the necessary problem-solving skills that the course demands. The application of Newton's second law was found to be particularly problematic through document analysis of South African examination feedback reports, as well as from an analysis of the physics examinations at a pair of well-resourced South African independent schools that follow the Independent Examination Board curriculum. Through an action-research approach, a resource for use by students was designed and modified to improve students' understanding of this concept, while modelling problem-solving methods. The resource consisted of brief revision notes, worked examples and scaffolded exercises. The design of the resource was influenced by the theory of cognitive apprenticeship, cognitive load theory and conceptual change theory. One of the aims of the resource was to encourage students to translate between the different representations of a problem situation: symbolic, abstract, model and concrete. The impact of this resource was evaluated at a pair of schools using a mixed methods approach. This incorporated pre- and post-tests for a quantitative assessment, qualitative student evaluations and the analysis of examination scripts. There was an improvement from pre- to post-test for all four iterations of the intervention and these improvements were shown to be significant. The use of the resource led to an increase in the quality and quantity of diagrams drawn by students in subsequent assessments.

TABLE OF CONTENTS:

LIST OF TABLES:

LIST OF FIGURES:

ABBREVIATIONS:

CAPS	Curriculum and Assessment Policy
DBE	Department of Basic Education
FCI	Force Concept Inventory
IDC	Itemised Data Capture
IEB	Independent Examination Board
IPPs	Isomorphic problem pairs
MCQ	Multiple choice questions
NL2	Newton's second law
NSC	National Senior Certificate
QUAN	An emphasis on quantitative methods in a mixed methods approach
QUAL	An emphasis on qualitative methods in a mixed methods approach
quan	A lack of emphasis on quantitative methods in a mixed methods approach
qual	A lack of emphasis on qualitative methods in a mixed methods approach
SELF	Strategies for Engaged Learning Framework
TIMSS	Trends in International Mathematics and Science Study

STYLISTIC CONVENTIONS:

‘ ’	used when a term from a source or from the field is used
“ ”	used to indicate quoted text
Italics	refers to new terminology or emphasis

Dedication

For my family: with love and gratitude.

Acknowledgements

To my family, friends and colleagues for their support and encouragement

To my supervisors for their guidance, support and enthusiasm

To The Schools for their support of this study

To my students

Do your little bit of good where you are; it's those little bits of good put together that overwhelm the world.

Desmond Tutu

CHAPTER 1

INTRODUCTION

"A physics student who lacks a conceptual understanding of physics and who is working physics problems is akin to a deaf person writing music or a blind person painting." (Hewitt, 1983, p. 309)

Many students at high school struggle with physics, and misconceptions are prevalent in many sections, persisting even after concepts have been taught at school and university (Hung and Jonassen, 2006; Nersessian, 1989; Van Heuvelen, 1991a). For this reason, teaching needs to be deliberate and intentional, based on an understanding of how students learn, and mindful of misconceptions and their origins. Having taught physics at an independent South African high school for thirteen years, I have gained some insights into students' difficulties and misconceptions in physics. I undertook this study to augment my experience with research and extensive engagement with the literature in order to understand why these problems occur and to help students to overcome them.

It has been said that if you give a man a fish, you feed him for a day. However, if you teach him how to fish, you feed him for a lifetime. Many of the students in my high school physics classes want me to show them how to solve each problem that they encounter or to provide a set of rules and exceptions that they can apply to *that* problem when they encounter it again. However, as every problem is different, or appears in different guises, one set of rules cannot be applied to them all. An understanding of the fundamental principles of physics is necessary so that these can be applied appropriately to any problem. The aim of this study was to develop a set of resources that would guide my students - and perhaps other students - to a deeper understanding of the fundamental principles of a topic that is generally poorly understood, so that they can apply these principles because they make sense, rather than relying on memory or algorithms.

This study was undertaken for personal growth, but also professional development and was funded by the school at which I teach. The school remains anonymous throughout the study to allow me to adopt a critical view of my teaching and my research. As the majority of my students are under the age of 18, careful ethical considerations were necessary and these are detailed in Chapter 3.

1.1 Rationale for Research

Physics is recognised as conceptually challenging and, as such, is often considered a gateway subject for further study in a range of tertiary courses (including science, medicine and engineering). As David Hestenes (2013) describes in his article *Remodeling Science Education*:

> *"Rapid emergence of a global economy driven by science and technology has precipitated a crisis in the education systems of all nations. Radical education reform is needed to produce (1) science literate citizens and consumers, provide (2) workplace readiness (the technical foundation for an effective workforce), and maintain (3) a technology pipeline (educating scientists and engineers to sustain economic growth)." (Hestenes, 2013, p. 13)*

Poor performance in physics is thus a limiting factor in supplying key science-dependent employees in the future, including competent science teachers, so perpetuating the cycle. As physics is a prerequisite course for many degrees in the sciences, a poor grounding in physics can affect the number of students able to complete these degrees. Leaving misconceptions and poor understanding of concepts unchecked at high school level can have an impact on throughput and success later on.

We do not only need scientifically-grounded students to study further, but we also need a population of students emerging from our schools with the skills of independent learning, problem-solving and scientific competence to equip them for the world that they will encounter after school, which is ever-changing (Angell et al., 2004; Juan et al., 2016; Redish, 1994; Reif, 1978).

In the South African context, the Physical Sciences Curriculum and Assessment Policy Statement (CAPS) for Grade 10 – 12, states that

> *"Physical Sciences prepares learners for future learning, specialist learning, employment, citizenship, holistic development, socio-economic development, and environmental management. Learners choosing Physical Sciences as a subject in Grades 10-12, including those with barriers to learning, can have improved access to: academic courses in Higher Education; professional career paths related to applied science courses and vocational career paths. Physical Sciences plays an increasingly important role in the lives of all South Africans owing to their influence on scientific and technological development, which are necessary for the country's economic growth and the social wellbeing of its people.' (Department of Basic Education, 2011, p. 8)*

The growth of science and technology in South Africa is particularly important as it is a developing country (Juan et al., 2016). Unfortunately, the ideals of the Department of Basic Education, articulated in the CAPS above, are not being met, as evidenced by research such as the Trends in International Mathematics and Science Study (TIMSS). TIMSS assesses the level of conceptual understanding that students have attained in science and mathematics which they are expected to have covered by Grade 8. South Africa administers the test in Grade 9 and was ranked last out of the 39 participating countries in the science score in 2015 (Reddy et al., 2017). In 2005, the Human Sciences Research Council (HRSC) *Study of demand and supply of educators in South African public schools,* commissioned by the Education Labour Relations

Council South Africa (ELRCSA), estimated that 18 000 – 20 000 teachers leave the profession each year in South Africa, while there are only 6 000 – 10 000 new teachers graduating (Modisaotsile, 2012).

The Independent Examination Board (IEB) (2018) has reported a decline in the number of students sitting the National Senior Certificate (NSC) examination in Physical Sciences (Figure 1.1). This may be exacerbated in the near future by the ruling by the Department of Basic Education (DBE) that from 2019 students who offer Mathematical Literacy may not offer Physical Sciences[1] (Department of Basic Education, 2017).

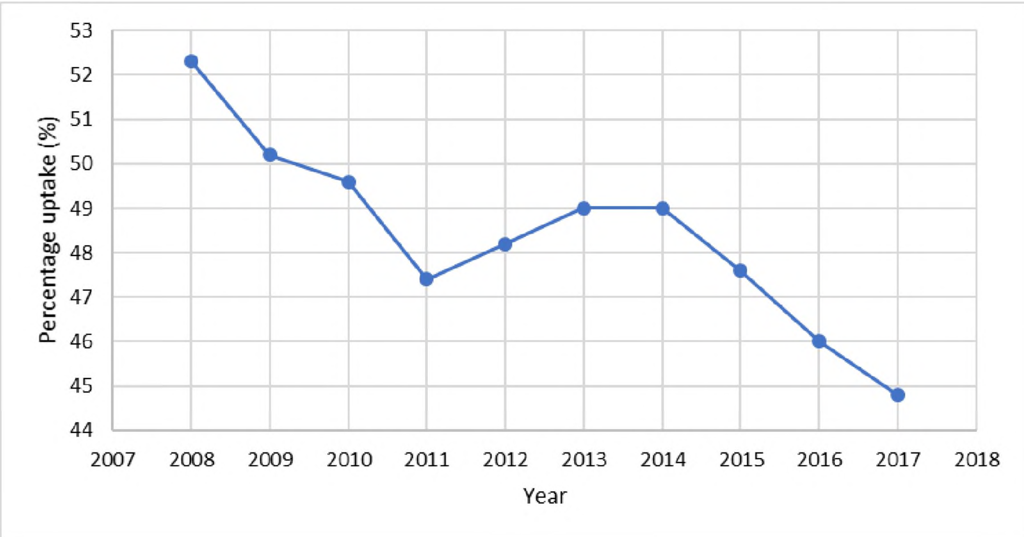


Figure 1.1: *Percentage uptake of Physical Sciences among IEB NSC candidates (2008 – 2017)*[2] (Independent Examinations Board, 2018) *See Appendix A.6.*

[1] The term 'offer' is used in DBE circulars to mean 'take'.
[2] Note that the scale for percentage uptake on this graph does not begin at 0.

1.2 Research Aims and Objectives

The aims of this study are to verify, with quantitative and qualitative data, which physics topics of the South African high school Physical Sciences curriculum are most problematic and then to develop and evaluate a targeted action-research intervention in these poorly understood physics concepts.

There is a considerable body of research on a variety of approaches that have been found to be successful in improving students' understanding of physics, particularly in introductory physics courses, and the intervention draws on these. Physics is fundamentally the same conceptually, whether at university or school, just mathematically more advanced at higher levels of study. Introductory courses at university encounter the same problems as students encounter at school (Huffman, 1997). This study was conducted in a high school setting, with a focus on learning, rather than on teaching. My hope is that this research may prove useful to other teachers who wish to gain insight into how students learn physics, as well as those responsible for curriculum development.

The objectives of the study were to

- identify physics concepts in the South African Physical Sciences curriculum that are generally poorly understood
- gain insight from literature as to why these concepts may be poorly understood
- gather approaches used by others to improve students' understanding of these concepts
- develop a resource to improve students' understanding of a concept
- assess the effectiveness of this resource.

The research design employed mixed methods, which are described in more detail in Section 3.2.2 of Chapter 3. Data sources included examiner reports, summaries of results, examination and test scripts, pre- and post-tests and evaluation forms. The resource used for the intervention was developed through an iterative action-research process.

1.3 Research Questions

To clarify the research objectives of this study, the following questions are asked:

Question 1: What are the physics topics that are most problematic in the South African Physical Sciences curriculum?

Question 2: Can students' performance be improved through the use of a targeted intervention in one of these problematic topics: the application of Newton's second law?

1.4 Significance of the Research

There is value in researching how students effectively learn physics in order to improve teaching practices. Rather than creating resources on 'gut-feel' or based on what *might* work, it is important that teaching methods and learning materials are designed and developed based on analytical academically tried concepts (Reif, 1978).

Physics Education Research was pioneered by a group of academics and teachers, passionate about instructional design, led by Lillian McDermott in the 1980s. They began to formally research the teaching and learning of physics and publish their findings. Their focus has been on conceptual understanding and scientific reasoning, rather than on quantitative problem-solving or memorisation (Rosenblatt, Heckler and Flores, 2013). The community of physics education researchers has produced extensive literature on a range of strategies for improving conceptual understanding and problem-solving skills among physics students, having also studied and documented the difficulties that students experience when trying to learn physics. Tools have been developed to test conceptual understanding, such as the Force Concept Inventory (FCI) (Hestenes, Wells and Swackhamer, 1992) and many others available through https://www.physport.org/ (AAPT, 2019).

Although the literature mostly documents research in introductory physics courses at universities and American colleges, there is evidence that the same problems exist in high schools (Mualem and Eylon, 2010). This study will add to the South African literature on Physics Education Research at schools.

The resource developed during this study could be used independently by students who do not understand a concept the first time and wish to revisit it, or who have missed lessons for whatever reason. It could also be used by students in schools without science teachers. In the broader South African context, students regularly miss school for reasons often dictated by their socio-economic circumstances and many schools do not have suitably qualified or trained science teachers. The 2015 TIMSS found that 61% of students were taught science by a teacher with a degree (Reddy et al., 2017), not necessarily a science degree. The resource should be accessible to students (in language and difficulty level) and suitable for independent use. My hope is that if students take greater responsibility for the development of their own understanding, using resources provided, they may become more independent learners and improve their confidence in the subject.

CHAPTER 2

REVIEW OF LITERATURE

"What we teach is important, but it must be viewed in the context of what our students learn." (Redish, 1994, p. 796)

This chapter outlines the predominant thinking in the field of Physics Education Research relating to this study. It begins by defining and explaining the key concepts and terminology frequently used in the literature in this field. This is followed by a description of the theories on learning that frame this study and a short note on additional factors that have been shown to affect students' ability to learn physics. The problems with conceptual understanding and learning physics are then outlined, mentioning those areas reported in the literature to be most problematic. Lastly, there is a discussion of the prominent solutions that researchers in the field have tried, in order to improve students' understanding of physics. These guided the development of the resource evaluated in this study.

2.1 Prominent ideas and terminology from relevant literature

The findings of academic research are often written in a style or in language that makes them difficult to access and understand. Stephen Kemmis writes in the editorial in The Action Research Reader that when developments are not accessible to practitioners it "creates a gap between those who possess knowledge which claims to be of vital importance in the development of practice and those who must have it for their work" (Kemmis and McTaggart, 1997, p. 28). In order to make this study accessible to physics teachers, to be easily read and understood, the academic jargon has been kept to a minimum. However, there are phrases and ideas particular to the field that appear in the literature and are pivotal to an understanding of this area of research. The meaning of the terms that are prevalent in the writing of this field is explained in this section.

2.1.1 Conceptual understanding and transfer

Concepts are understood when they can be applied in a similar or new context. A student may be able to memorise information and repeat it, but this does not indicate that they understand it. To demonstrate understanding, they need to apply the concept. This application is called *transfer* and is often a measure of whether conceptual understanding is present or not (Yerushalmi et al., 2009).

2.1.2 Isomorphic problems

Isomorphic problems are problems that require the application of the same physics principle to solve them, but may differ in their *surface characteristics*. (Singh, 2008b). The surface characteristics of the problem are the details, such as context, which do not affect the physics. For example, a crane lifting a load with a cable and a car towing a boat up a slope have different surface characteristics, but Newton's second law could be applied to both problems to determine the tension in the cable. Isomorphic problems may be presented to students to test transfer or conceptual understanding or they might be used to help students with conceptual understanding (Section 2.5.11), worked examples (Section 2.5.8) and categorisation (Section 2.5.12).

2.1.3 Problem-solving

Maloney (2011, p. 3) uses this definition of a problem, given by Hayes in his 1981 book called *The Complete Problem Solver:* "Whenever there is a gap between where you are now and where you want to be, and you don't know how to find a way across that gap, you have a problem". A definition that is perhaps more specific to physics describes a problem as a situation that is new or unfamiliar, which can be solved or overcome through effort and the use of knowledge and experience (Anderson, 1993; Ince, 2018).

Problem-solving is often used to assess understanding of physics as it may be seen as the application of physics concepts in real situations and is considered a highly valued skill (Sweller, 1988). Problem-solving should also be a learning opportunity (Cohen et al., 2008) and many of the approaches described below make use of it as such.

Problems in physics may be categorised as well-defined or ill-defined, qualitative or quantitative, routine, multistep, single-step or anything on the continuum between these extremes (Maloney, 2011; VanLehn, 1988). Often physics problems are said to be '*context-rich*', which means that the problem is situated in a real-world context, where the value that needs to be calculated may not be explicitly identified. In such problems, extra information may be given and the problem solver needs to decide what information is relevant and applicable (Heller and Hollabaugh, 1992; Huffman, 1997).

The procedures and strategies that can be employed in problem-solving are referred to as *heuristics*.

2.1.4 Scaffolding

Scaffolding is the provision of additional steps, information or guidance through the process of problem-solving (Dawkins, Hedgeland and Jordan, 2017). A building analogy is helpful in thinking about scaffolding: it is a temporary platform that helps in the construction of a permanent structure. So, in learning, scaffolding is provided temporarily while it is needed for problem-solving and then removed once knowledge structures are in place and it is no longer necessary. It is important that the scaffolding is appropriate to support learning and in line with students' prior knowledge and skills (Lin and Singh, 2015). To take the building analogy one step further, it is important that the scaffolding supports the current structure and is not at a different level from the current structure, nor that the steps of the scaffolding are too large to climb easily. There are a number of ways in which scaffolding can be used, as summarised in Table 2.1 below.

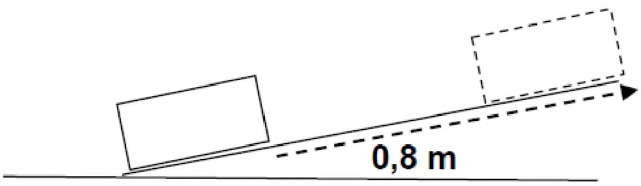
Table 2.1: *The 6 elements of scaffolding (bold), with itemized examples of how each element is likely to appear in written physics problems (Dawkins et al., 2017, p. 5).*

Use of representations and language to bridge expert-novice understanding 1. Technical words are described in everyday language 2. Mathematical symbols are explained in words 3. A diagram is used to give meaning to technical words or symbols
Reduction of cognitive overhead 4. Includes a math (or other background) reminder 5. Somehow automates a routine task (e.g. unit conversions given, constants given that could have been looked up) 6. No penalty for missing significant figures, wrong unit, wrong numeric value or other nonsalient component of the question 7. Provides a diagram or graph that the student could have constructed with the available information
Insertion of expert knowledge 8. Expert directed focus is used (e.g. key information is highlighted using bold or italicized text) 9. Explicitly instructs student to make an expert assumption (e.g. "you may ignore air resistance") 10. The student is warned of a common mistake or relevant misconception
Ordered task decomposition (provide structure for complex tasks) 11. Each part of the question contains only one expected output (numeric or otherwise) 12. An output (numeric or otherwise) is required in subsequent work 13. Marks are awarded for interpreting outputs (no further calculation required) 14. Question has a wide mark distribution (each part is worth less than 50% of the total awarded marks)
Conceptual prompting 15. Asks student to define or explain an equation that they should use 16. Asks student to identify a concept that they should make use of 17. Asks a student to draw a diagram before beginning the problem
Reduction of degrees of freedom 18. Gives student the appropriate equation to use 19. Prompts at how the question is expected to be solved (e.g. "using the principle of conservation of energy…") 20. Explicitly instructs student on how to begin a task

Although all the means of scaffolding described in Table 2.1 are used in problems at various times, the term '*scaffolding*' in high-school physics problems often means breaking a large task down into smaller, more manageable tasks, usually by an expert or more knowledgeable person (Dawkins, Hedgeland and Jordan, 2017).

As an example, consider this problem:

> A box (mass 40 kg) is given a push up a slope, travelling up the slope at 3 m/s just after the push. The box comes to rest 0,8 m from the point where the force was removed.



The question could ask for the coefficient of sliding friction between the box and the slope. This would be a multistep calculation, which would require the student to have a very clear understanding of the steps required to reach this answer. More commonly, a question like this would be *scaffolded*, particularly in high school physics, for example:

- State the work-energy theorem.
- Calculate the net force acting on the box
- Draw a free-body diagram of the forces acting the box
- Determine the frictional force acting on the box
- Calculate the coefficient of friction between the box and the slope.

2.1.5 Misconceptions

Students are not blank slates. They enter any physics course with a lifetime of experiences – and explanations for these experiences – which have shaped their understanding of the physical world. Unfortunately, these ideas often conflict with 'proper physics' (Maloney, 1990), and research has shown that these strongly held preconceptions need to be confronted and challenged, or they will remain unchanged (Van Heuvelen, 1991a).

diSessa (1993) conceptualised what he called 'phenomenological primitives' (p-prims), which are particular, small basic knowledge structures, which originate from experience. These are often used in clusters or in combination with other kinds of reasoning. P-prims are sometimes used when explaining the preconceptions of students or 'knowledge in pieces' (diSessa, 1993). These conceptual building blocks are recognised when they are encountered and prompt a specific reaction or retrieval from memory, if they are familiar. An example might be the term 'velocity', which, when read by someone familiar with it, will prompt the retrieval of a series of connections or related reactions, such as 'vector', 'rate of change of displacement' or, in the context of a problem, perhaps an equation or problem-solving approach.

There is a large body of research on 'intuitive physics', where conceptual understanding of physics does not fit a modern understanding of physics. These are often referred to as *misconceptions*, *preconceptions, existing conceptions* or *alternative conceptions* (Potgieter et al., 2010; Kural and Kocakülah, 2016), rather than 'incorrect' because they are based on the students' experiences with the world, which have been adequate for their needs up to that point and so are not incorrect in their experience (Potgieter et al., 2010).

This study will use the term '*misconceptions*', as these are incorrect assumptions and ideas, and it is the aim of this study to investigate ways to address and correct these misconceptions. Misconceptions result from everyday interactions and are resistant to change, requiring deliberate restructuring to be set right (Hung and Jonassen, 2006; Van Heuvelen, 1991a). Students need to recognize inconsistencies or conflict in their conceptual understanding and then be guided through a process of reflection to refine and reorganise their knowledge (Lin and Singh, 2015).

Interestingly, the preconceptions that students hold and the difficulties that they encounter in each topic are not as varied as one might think. Based on the conclusions of the paper on *Judgement under Uncertainty* (Tversky and Kahneman, 1974), Singh and Schunn (2009) explain that this may be because our everyday experiences and processing of these experiences is very similar.

2.1.6 Schema acquisition

The skill of problem-solving is largely dependent on schema acquisition (Sweller, 1988). Sweller and Cooper (1985) and then Paas (1992) defined a *schema* as a "cognitive structure that enables problem solvers to recognise problems as belonging to a particular category of problems that require particular operations to reach a solution (Paas, 1992. p. 429). So schemas guide the decisions as to which principles to apply in future problem-solving situations, where similarities are found (Paas, 1992).

There is no evidence that solving large volumes of problems improves problem-solving skill (Sweller and Cooper, 1985) or conceptual understanding (Kim and Pak, 2002). However, with repeated exposure and experience, problem-solving sequences can be grouped in familiar 'chunks' that become recognisable as a single unit that can be applied to solve similar problem sequences in the future (Larkin et al., 1980; Sweller, 1988). This 'chunk' is stored in the problem-solver's memory and, when triggered by a familiar or recognised stimulus, calls up the memory of a sequence of steps or a strategy

(Larkin et al., 1980). An increase in skill and, eventually, mastery develops through the storage of more schemas that are increasingly complex, as schemas are combined to be stored as larger ‘chunks’ (Paas, Renkl and Sweller, 2004).

2.1.7 *Novice vs Expert approaches to problem-solving*

Research on chess players revealed a distinction in the number of realistic chess moves remembered by master chess players compared to novice players. Both sets of chess players remembered sequences of moves in ‘chunks’, and there was found to be little difference in the number of chunks remembered by masters compared to novices, but rather in the size of the chunks. Master chess players stored the sequence of possible moves in much larger chunks (Sweller, 1988). The consequence of this can be transferred into learning.

Students in most ordinary introductory physics courses adopt a novice-like approach to problem-solving (McDermott, 1993). Experts in physics have a greater store of knowledge items in their memories, which they can draw from when presented with a problem (Larkin et al., 1980). Expert problem-solvers are able to apply previously acquired schemas to new problems (Sweller and Chandler, 1991). Experts also have a systematic structure to their knowledge, seeing the relationships and similarities between stored pieces of information. In contrast, novices tend to have little structure to their knowledge and often do not see the links between information and so are unable to locate the appropriate concepts for solving problems (Van Heuvelen, 1991a). Novices have also been shown to use symbols more than experts, in that novices often search for and manipulate formulae without understanding the conceptual meaning of the symbols and formulae (Dhillon, 1998).

Larkin wrote that

> *"The expert is not merely an unindexed compendium of facts, however. Instead, large numbers of patterns serve as an index to guide the expert in a fraction of a second to relevant parts of the knowledge store. This knowledge includes sets of rich schemata that can guide a problem's interpretation and solution and add crucial pieces of information. This capacity to use pattern-indexed schemata is probably a large part of what we call physical intuition." (Larkin et al., 1980, p. 1342)*

When faced with an unfamiliar problem, novices and expert problem-solvers are inclined to approach it differently. Expert problem-solvers initially analyse a problem statement and then decide what principle or approach would be appropriate to use, while novices look at the features or context of the problem to identify an approach (Chi, Feltovich and Glaser, 1981). Novice problem-solvers work backwards from the goal to solve problems, using what is called '*means-end analysis*', while experts work forward from the information they are given, towards a solution (Huffman, 1997; Larkin et al., 1980; Paas, 1992; Sweller, Mawer and Ward, 1983; Sweller and Chandler, 1991).

The *means-end approach* aims to solve a problem through the pursuit of a series of sub-goals, attempting to get closer and closer to the 'final answer'. Often students manipulate equations until they determine values that they can use (Sweller, 1988). Unfortunately, this approach often overlooks the relationships between values and operations and does not benefit from any previously used problem-solving sequences. Problem-solvers using this approach also do not acquire schema as they do not categorise the problem conditions or recognise the connection between similar approaches (Sweller, 1988). Expert problem-solvers recognise the problem or solution process from experience and can follow the correct sequence of steps to reach the goal, working forward directly from the given information (Sweller, 1988).

The major differences between the problem-solving approaches of expert and novice problem-solvers are summarised in Table 2.2, below.

Table 2.2: *A summary of the major differences in problem-solving approaches between expert and novice problem solvers (Gerace, 2001, p. 2).*

Expert	**Novice**
Conceptual knowledge impacts problem-solving	Problem-solving largely independent of concepts
Often performs qualitative analysis, especially when stuck	Usually manipulates equations
Uses forward looking concept-based strategies	Uses backward-looking means-end techniques
Has a variety of methods for getting unstuck	Cannot usually get unstuck without outside help
Is able to think about problem-solving while problem-solving	Problem-solving uses all available mental resources
Is able to check answer using an alternative method	Often has only one way of solving a problem

2.2 Physics learning theories

> *"In the area of logico-mathematical structures, children have real understanding only of that which they invent themselves, and each time that we try to teach them something too quickly, we keep them from reinventing it themselves." (Almy, Chittenden and Miller, 1966, quoted in Bybee and McCormack, 1970; p. 15)*

To prepare resources that improve learning, it is helpful to better understand how students learn. Learning by discovery allows students to produce a sound cognitive structure (Egan and Greeno, 1973) and the constructivist approach has gained traction in education. Constructivism emphasizes the active role of the student in building their understanding by interpreting their experiences (Anderson, 1992). Because every student constructs their own understanding, these understandings, and the paths to understanding, are likely to differ between individuals. Anderson (1992) emphasises that the construction of scientific understanding needs to be validated against observations. To be integrated and retained, new knowledge needs to fit with existing knowledge and experience (Driver et al., 1994). Knowledge is introduced in a context where it is used, and students are first encouraged to learn to use and understand the knowledge and then expand their understanding sufficiently so that they can apply the knowledge in a variety of contexts (Collins, Brown and Newman, 1987).

Four theories, underpinned by the constructivist view, are applicable to this study: Greeno's model of problem-solving and reasoning (Greeno, 1989), the theories of cognitive load (Sweller, Mawer and Ward, 1983), cognitive apprenticeship (Collins, Brown and Newman, 1987) and conceptual change, based on the work done by Piaget (Posner et al., 1982). Each of these theories presents a view that can be applied to aspects of learning physics: Greeno's model of problem-solving and reasoning, the theory of cognitive load and the theory of conceptual change provide insight into the learning process, while cognitive apprenticeship provides a useful model for an effective teaching approach. Johnstone (2009) urges researchers to put their pedagogical differences away and remember that they are all striving to better understand and improve learning. Thus, this study focuses on the aspects of each theory that can be applied to learning physics rather than on the broader philosophical and theoretical views.

2.2.1 *Greeno's model of problem-solving and reasoning*

Subjects such as mathematics and physics organise information in a structured way, according to concepts. In order to use an appropriate piece of knowledge, students need to target the relevant section or domain of the subject and retrieve the piece of knowledge that is required (Greeno, 1989).

James Greeno (1989) proposed a relational structure of what he termed "situated activity and reasoning" (Greeno, 1989), based on the philosophy that all human activity is situated in the context in which it occurs. Problem-solving and reasoning require connections between the four domains (as shown in Figure 2.1 below): concrete (the physical context), symbolic (using representations involving symbols), model (using diagrams or visual representations) and abstract (conceptual) (Gaigher, Rogan and Braun, 2007).

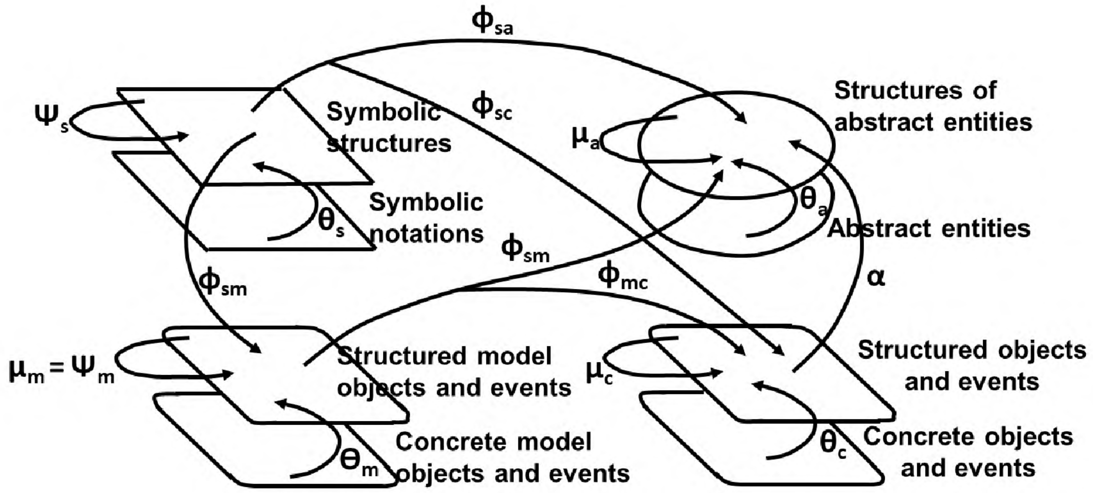


Figure 2.1: *Greeno's model of the domains of problem-solving (Greeno, 1989 p. 24).*

A common physics context may provide a way of explaining the domains in a more accessible way (Gaigher, Rogan and Braun, 2007). The context could be a crane raising a load, as shown in Figure 2.2. The crane, the cable and the load are the *concrete objects* (bottom right in Figure 2.2): a person could interact with them and manipulate them and view them as a system of *structured objects* (parts of a system). They are experiencing forces and there are forces between them. The mass of the load, and the forces are *abstract entities* (top right in Figure 2.2) that we can reason about theoretically, but cannot interact with directly. These abstract entities are brought together into *abstract 'structures'*, linking the abstract entities. The state of the load (and the crane) is described by Newton's second law, an abstraction, which provides a means of explaining or describing the behaviour of the system. The relationship can be described with symbols, with a *structured symbolic* representation (top left in Figure 2.2). The system can be modelled using a free-body diagram, the *structured model* of objects (bottom left in Figure 2.2).

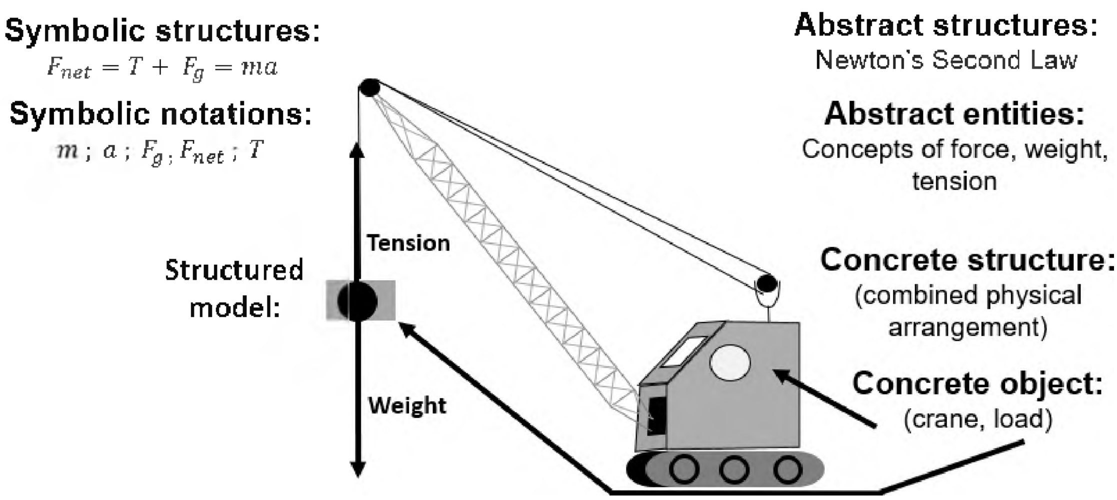


Figure 2.2: *A typical physics context to illustrate Greeno's domains.*

Greeno's (1989) model is described and explained in the following few paragraphs. The context to which the symbolic domain refers is shown on the lower right of Figure 2.1. The *concrete objects and events* (lower level in Figure 2.1) represent the physical components of the situation, while the *structured* *objects and events* (upper level in Figure 2.1) represent their organisation or a representation of their interaction in an activity (Greeno, 1989). Mirroring the relationships between the symbolic expressions, the way that the components interact can be indicated by Θ_d (e.g. a collision or contact), while μ_C refers to the operations or actions performed on the concrete objects in a situation to result in the activity or structure represented in the upper level (e.g. a force being applied).

The symbolic domain (upper left in Figure 2.1) comprises descriptions or depictions, referring to the component parts. These are further differentiated into *symbolic notations* (lower level in Figure 2.1), which are the marks on paper or the symbols in an equation with which we represent variables or quantities in a concrete situation, and *symbolic structures* (upper level in Figure 2.1), which are organised structures or expressions, often describing relationships or theories (e.g. $F_{net} = ma$, which consists of variables or symbols linked together) (Greeno, 1989). These symbolic structures can often be rearranged (e.g. $a = \frac{F_{net}}{m}$) while keeping them true and these transformations are indicated by Ψ_S. The relations between the notations and the structures are given by Θ_S.

The connection Φ_{sa} shows the link between the symbolic domain and the objects and events (the concrete domain) that they represent. Without this connection, the meaning and context of the symbols is lost. Often students struggle to apply their 'text-book knowledge' of symbols, equations or formulae to real world problems. They may be familiar with the marks on paper and much of our instruction centres on the skills of manipulating these (Ψ_S) and their relationships (Θ_S), without elucidating the link between these symbols and notation and their context (Φsa). Students may even come to believe that the symbolic structures that we construct describe the variables, rather than real, concrete entities. Their understanding is disconnected from its context.

To make sense of a problem or a situation, we need a coherent representation to visualise situations and make inferences. This may be a mental model or other representation which is not denoted by either the symbolic or concrete domains. These representations are characterised by the model domain (bottom left in Figure 2.1), with *structured model objects and events* (upper level) and *concrete model objects and events* (lower level). A model of objects and events could be a demonstration, a physical model (e.g. a model of the solar system to show the rotation of the Earth or planetary orbits) or a diagrammatic representation. A structured model might be a free-body diagram or a 'before and after' sketch of a collision. The manipulations within the model could involve the manipulation of the structured model components (μ_m) or the symbols in the model that denote other articles (Ψ_m). The model needs to be coherent with other representations, and any inconsistencies need to be addressed and adjusted by revising one of the representations, in order to ensure consistent representations.

In the top right of Figure 2.1 there is the abstract domain. This comprises the *abstract concepts* ('abstract entities' - lower level in Figure 2.1), such as velocity, acceleration and force, and their *relationships and structures* ('structures of abstract entities' - upper level in Figure 2.1). The function μ_a describes manipulations of abstract entities to predict the outcome of the manipulation or change. These operations should correspond to the relations between the physical features of the context (μ_c). The relationship between the concrete and the abstract is labelled α for abstraction (Greeno, 1989).

Greeno (1989) explained that what we call 'misconceptions' are mismatched or disconnected domains. He believed that mental models that allow us to make sense of a situation and infer the effect of changes to that situation will encourage connections, just as experts can relate different representations and recognise them as facets of the same scenario (Savinainen and Viiri, 2008). Students find it difficult to make the connections between the concrete representations, which are easier to understand, and the more abstract concepts, without specific instruction and support (Maries and Singh, 2017). This observation is supported by cognitive load theory, described below.

2.2.2 *Cognitive Load Theory*

Cognitive load theory is applied to the learning of tasks with high cognitive demand (Paas, Renkl and Sweller, 2004), which makes it an appropriate theory to apply to physics. John Sweller's (1988) initial work on cognitive load came about from studies using puzzle problems. The participants were able to solve multiple puzzles, but they were unaware of the rule that they were using to solve all the puzzles. Sweller's explanation for this was that their cognitive resources were allocated to the mechanics of solving the problems, rather than to the structure of the problems (Sweller, 1988; Sweller and Chandler, 1991).

The working memory is a vital component of learning. It is the part of a person's short-term memory where new information is processed, decoded or restructured and where it interacts with information retrieved from long-term memory through a search function (Johnstone, 2009; Phillips, 2018). New information is admitted through a person's unique filter, based on their interests, what is important and what makes sense to them (Johnstone, 2009). If the information can be linked to existing knowledge, it may be assimilated into schemas (Section 2.1.6), which would result in learning and can be stored in long-term memory for future retrieval (Sweller and Chandler, 1991). Figure 2.3 shows Johnstone's (2009) model of learning, based on information processing, which incorporates the 'working space' proposed by Piaget's students (Johnstone, 2009).

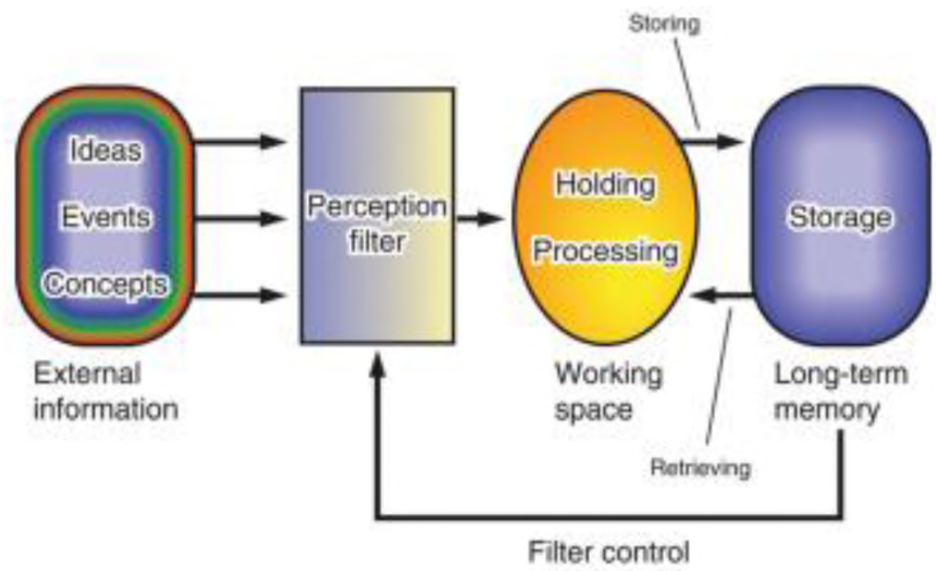


Figure 2.3: *Johnstone's (2009) model of learning (Johnstone, 2009, p. 23).*

This working memory space is limited. It can be used to hold information temporarily, as well as to process it. If a large amount of information has to be held, there is limited space for processing, whereas if a large amount of processing is required, little information can be stored (Johnstone, 2009). Should a task require a large volume of information to be stored or processed simultaneously, cognitive overload is experienced (Sweller, 1988). The capacity of the working memory is thus the limiting factor in the volume of new conceptual information that we can process and the pace at which it is integrated (Sweller and Chandler, 1991).

Cognitive load is a combination of mental load (dependent on the task and the information provided) and mental effort (determined by the cognitive resources available to the task) (Paas, 1992). Cognitive load is subjective (Singh, 2009) and the load experienced or perceived by students varies with their stage of learning. A task for a beginner learner would be too simple for learning to occur in an advanced learner. Performance and learning are reduced in situations of either excessively low cognitive load (underload) or high load (overload) (Paas, Renkl and Sweller, 2004). Learning is optimal when the learning task is designed to integrate new information with existing knowledge in a way that limits the cognitive load to a level that can be accommodated by the working memory (van Gog, Paas and Sweller, 2010).

Learning tasks should limit high or excessive cognitive load where students may be overwhelmed by the complexity of the task or by the amount of information that they are required to process simultaneously (Paas, 1992; van Gog, Paas and Sweller, 2010). This overload can inhibit optimal learning. Tasks should be designed so that the working memory is devoted to tasks that contribute to learning (*'germane' load*) and not drained by processes that overload the working memory (*'ineffective' or 'extraneous' load*) (van Gog, Paas and Sweller, 2010).

Even the processing of redundant information uses cognitive resources, so instructions and information provided should direct the attention of students to the critical content to aid learning (Paas, 1992). If the redundant information is integrated with essential information, for example in the context of a problem statement or question, it will be processed. This results in an extraneous cognitive load provided by the unnecessary information (Sweller and Chandler, 1991). Incoherent or conflicting information presented separately that hinders learning is called the 'split-attention effect', which can be countered by ensuring that the information is well-integrated (van Gog et al., 2009).

Schell and Butler (2018) explain that retrieving and processing information from long-term memory changes the knowledge that is returned to memory, which results in learning or the acquisition of schemas. For this reason it is ideal to present information to students in a form that requires restructuring, such as requiring students to construct representations of the concepts or information supplied (Sweller and Chandler, 1991).

Schemas are constructed and automated through practice and repetition. Once a schema is 'automated', it can be unconsciously retrieved from long-term memory to be processed alongside new information, which frees up working memory capacity (Paas, Renkl and Sweller, 2004; Schell and Butler, 2018). Thus when the content that it is processing is familiar, working memory is unrestricted and without limit (Sweller and Chandler, 1991).

The value of repeated retrieval of information, in strengthening these retrieval pathways and promoting the transfer of learning, suggests that retrieval practice should be included in student activities in instructional models such as peer instruction (Schell and Butler, 2018) and self-testing (Larsen, Butler and Roediger, 2013). Retrieval practice in tests has been shown to improve transfer of learning to new contexts (Carpenter, 2012) and long-term retention (Larsen, Butler and Roediger, 2013).

While problem-solving promotes retrieval of information, the process of solving problems may not be effective in learning, and may even interfere with schema acquisition, if cognitive resources are directed to solving the problem, rather than learning from it (Sweller, 1988). Worked examples, particularly if accompanied by commentary, can encourage a focus on the processes and guide students to classification according to physics principles, assisting schema acquisition (Sweller and Chandler, 1991). Characterising problems can reduce the extraneous load imposed when students are faced with a large number of seemingly diverse problems (such as encountered in 'means-end' analysis) (Sweller and Chandler, 1991).

In Section 2.1.7 the 'means-end' analysis was described, which is often used by novice problem-solvers. Adopting a means-end analysis when solving problems results in high cognitive load as the student needs to consider simultaneously the 'goal state' (desired outcome), the problem state, the necessary operators linking them, the relationships between goal state, problem state and the operators, as well as the intermediate sub-goals. The decisions of what to do next place considerable load on the working memory of the novice problem solver, particularly as they see a problem as a series of sub-goals, which require management (Larkin et al., 1980). This leaves no cognitive resources available for schema acquisition (Sweller, 1988).

When the means-end approach is used, cognitive resources are spent on activities and processes that do not lead to schema acquisition as the categorisation of problems is not possible when each problem-solving pathway in different. This makes this approach an inefficient way to learn (Paas, 1992; Sweller, Mawer and Ward, 1983; Sweller and Chandler, 1991). Experts, on the other hand, typically have more knowledge that they have compiled and can access with greater ease, allowing them the excess cognitive resources for reflection or metacognition while they solve problems (Singh, 2004).

2.2.3 Cognitive Apprenticeship

The development of skills for problem-solving and conceptual knowledge are often abstracted from real-world context and viewed as separate and often irrelevant to students' experiences. Students do not solve a problem using intrinsic logic or strategy, but rely on methods dictated by text books, which limits them to solving only identical or very similar problems (Collins, Brown and Newman, 1987). The theory of cognitive apprenticeship was developed to address this. It teaches the processes followed by experts and supports the development of deep conceptual knowledge in various contexts, woven together and linked to other concepts and contexts (Collins, Brown and Newman, 1987).

Collins et al. (1987) expanded on the model of apprenticeship described by Lave and Wenger in 1991 who wrote about teaching professional skills through social participation. Collins et al. (1987), like Greeno (1989), emphasizes the importance of learning in a social context. Learning happens through a process of 'modelling', 'coaching', 'scaffolding', 'articulating', 'reflection' and 'exploring'. The students observe the master *modelling* a behaviour or activity, making the process explicit. The students then attempt the process themselves under the guidance of the master. In this *coaching* phase, the master provides scaffolding, feedback and prompts to guide and support the students as they acquire the skills. *Scaffolding* may involve prompts and reminders or working alongside the students to assist with tasks that they cannot yet perform on their own. Students are encouraged to *articulate* their knowledge, reasoning and understanding, which allows the master to gauge their progress and requires the students to order their thoughts. They are also guided through a process of *reflection* on their problem-solving, comparing it to that of an expert or of peers. Finally guidance and feedback are gradually withdrawn, with the expert providing only direction and refinements, as the students (or apprentices) gain skill and develop self-reliance through *exploring* new problems independently (Collins, Brown and Newman, 1987; Mason and Singh, 2016b; Singh, 2008c).

Experts usually model problem-solving techniques and approaches. There is value in this approach as novice problem solvers can learn the appropriate strategy under the guidance of an expert. By observing an expert, the novice learns to construct and then expand a conceptual model before attempting a problem. This improves efficiency in learning and integration of concepts and skills, as students do not merely practice isolated sub-skills (Collins, Brown and Newman, 1987).

As they model the appropriate approach, experts are also modelling categorisation of problems in the way that they decide on an approach for each problem. This helps students to correctly allocate or 'file' feedback to the relevant concept or section and to develop a secure, structured knowledge base on which to construct schemas when they begin to do so (Collins, Brown and Newman, 1987). However, experts often perform some steps automatically or skip steps and need to consciously model good problem-solving processes and ensure that they are clear and explicit in their approach (Collins, Brown and Newman, 1987). It is also helpful to 'replay' the problem-solving process as performed by an expert and by a novice in a reflective comparison (Collins, Brown and Newman, 1987).

The metacognitive skills of self-explanation and self-correction play a vital role in learning through apprenticeship. As much as the master, expert or mentor guides the students through the process of learning the skill, the students learn to self-regulate and self-correct, as it is modelled for them through the coaching phase of apprenticeship. As they receive feedback, the students compare their approach and performance with the expert approach and learn to reflect on their process. This allows them to improve their performance and to grow towards independent problem-solving as they learn to self-correct and diagnose their own difficulties. They learn to anticipate the guiding or reflective questions asked, and develop the habit of asking themselves the same questions (Collins, Brown and Newman, 1987).

Although the emphasis so far has been on expert modelling, there is a place for group work in cognitive apprenticeship. This is seen as providing a valuable opportunity for modelling, articulation and self-diagnosis, as well as the opportunity to critically evaluate the strategies followed by others. It is also useful for growth in confidence as students see that they are not alone in their difficulties. A useful exercise is also to have an expert grapple with an unseen (difficult) problem in front of the students from time to time to model strategy when faced with a problem where the direct route to the solution is not immediately obvious (Collins, Brown and Newman, 1987).

2.2.4 Conceptual Change

In the 1970's Piaget explained learning as a process of assimilation and accommodation, where understanding is fluid and can be updated and refined. He likened learning to eating food (rather than the common analogy of a sponge soaking up water) as nutrients are absorbed and assimilated from the food that has been ingested (Sutherland, 1992).

George Posner, Kenneth Strike, Peter Hewson and William Gertzog (1982) proposed a theory of conceptual change in an attempt to better understand learning and students' misconceptions. Students apply their preconceptions when they encounter new information or new realities. To be accepted, the new information has to fit with the knowledge already constructed (Kural and Kocakülah, 2016). This first phase of conceptual change is called *assimilation* (Posner et al., 1982). When the students' preconceptions do not adequately explain the new phenomena, they are said to be in crisis and reorganise their existing conceptions, which is called *accommodation* (Posner et al., 1982). Thus, crisis is desirable as it has the potential to result in learning. Assimilation and accommodation result in a new *equilibrium,* and so the connections between the previous knowledge and new concepts are formed (Kural and Kocakülah, 2016; Sutherland, 1992).

This is an active process as the student connects new information to existing knowledge, but for it to be successful, teachers need to know what each student knows at the outset (Sutherland, 1992). This suggests that the path of learning and the provision of learning material could be unique for each student, strengthening the argument that teachers need to be facilitators of learning, rather than instructors or conveyers of knowledge. Students also need to engage and grapple with ideas and concepts that are in conflict with their present understanding to enable successful accommodation. Sometimes students need to have their understanding challenged, or reach a point where they are dissatisfied with their understanding, to be prompted to seek accommodation (Posner et al., 1982).

Often efforts to address misconceptions through ordinary teaching show limited success as conceptual change is needed (Nersessian, 1989). This method relies on teacher engagement, as the intervention is based on the preconceptions of their students. New, scientifically sound concepts need to be attached to 'anchoring conceptions', which are correct concepts that are already in place. This can be done through bridging activities, such as interactive demonstrations, which correct misconceptions (Kural and Kocakülah, 2016).

Conceptual change is the rational and progressive development of a model of understanding through refinement and restructuring (Carrejo and Reinhartz, 2014). Modelling is an important strategy for encouraging and assisting conceptual change, supported by the process of self-assessment and the evaluation of ideas through reflection. Conceptual change only occurs through cognitive conflict, which is generated through circumstances such as peer-interaction (Kural and Kocakülah, 2016).

2.3 The problem with teaching and learning physics

Physics is perceived by students to be difficult, regardless of their performance in the subject (Angell et al., 2004; Ekici, 2016). Physics students, particularly at high school level, consider the abstract nature of physics concepts difficult to understand (Ekici, 2016). Not only are the concepts often abstract and complex, but physics is also littered with strange-looking symbols and formulae that have precise meanings and are combined with rules that must be used correctly (Rosengrant, Van Heuvelen and Etkina, 2009).

There is a large body of literature documenting the difficulties that students experience in building a good conceptual understanding of physics (Huffman, 1997; Hewitt, 1983; Larkin et al., 1980; Gaigher, Rogan and Braun, 2007). Much has also been written on the difficulties that students experience with problem-solving. The conflict between teaching for conceptual understanding and teaching the skill of problem-solving is also well-documented (Smith, Mestre and Ross, 2010). Some authors argue that qualitative reasoning (conceptual understanding) is required to perform quantitative analysis (problem-solving) (Singh and Schunn, 2009) and some argue that problem-solving can guide students to understanding (Gaigher, Rogan and Braun, 2007). The quantitative and qualitative approaches are two sides of the same coin, which should not be viewed discretely, but seen as integrally linked (Hung and Jonassen, 2006).

Good performance in examination-type questions does not always mean that a student has good conceptual understanding (Hewitt, 1983; McDermott, 1991; Meltzer, 2002). Students can learn to perform processes without understanding the underlying principles (Greeno and Johnson, 1985) and may not be able to state the principles or explain how they are involved, or applied, in solving a problem. Kim and Pak (2002) found that even after solving over 1000 physics problems, students lacked conceptual understanding. The emphasis on computation and problem-solving in school courses, which is made clear by the nature of assessment, overshadows the quest for conceptual understanding (Hewitt, 1983; Mazur, 1995).

Students enter physics courses with prior knowledge or preconceptions and this prior knowledge either facilitates or interferes with learning (Halloun and Hestenes, 1985; Hestenes, Wells and Swackhamer, 1992; Redish, 1994). When students' preconceptions are in line with physics, they provide a foundation for constructing new knowledge, particularly if the existing knowledge structure is well-organised. When their prior knowledge differs or conflicts with accepted scientific explanations, they may have difficulty integrating new learning with their inaccurate preconceptions. These misconceptions may be highly resistant to change, remaining even after teaching to the contrary, particularly if they require restructuring (Hung and Jonassen, 2006; Nersessian, 1989; Van Heuvelen, 1991a). When students have incomplete knowledge, they can be guided to bridge the gaps in their understanding. The link from conceptual reasoning to quantitative reasoning is recognised to be cognitively demanding (Singh, 2008b), as is the skill of organising concepts into an internal knowledge structure from which they can be accessed (Reif, 1983).

Too often students try to solve physics problems with a formula sheet in one hand, picking any formula that seems to fit, without applying concepts appropriate to the context of the problem. The approach of picking a formula and plugging values into it does not result in conceptual understanding (Hung and Jonassen, 2006) or schema acquisition. Another common approach of novice physicists or students who struggle to apply physics concepts is to memorise, which is inefficient (Hestenes, 2013; Redish, 1994; Van Heuvelen, 1991a). Students who attempt to memorise and then appropriately apply problem-solving heuristics experience significant cognitive load. Repeated exposure to a concept assists to promote learning and strengthens the access path from memory. However, a content-rich curriculum often means that exposure to a concept is usually brief or once-off, which results in transient knowledge (Stott, 2013), which is usually insufficient for schema acquisition. Without the opportunity to explore each concept in a variety of contexts, shallow and inaccurate generalisations can be formed which result in misconceptions (McDermott, 1993). Hewitt (1983) also advocated teaching conceptual understanding and giving students enough time to master the concepts before teaching the skill of problem-solving. Multiple exposure to concepts over an extended period of time in different ways is needed to incorporate them into existing knowledge (Maloney, 1990; Van Heuvelen, 1991a).

Students need a coherent framework of knowledge, which does not usually result from traditional teaching (McDermott, 1993). They need not only to understand the concepts, but also to link them and see how they fit together. For example, to apply Newton's second law without an understanding of acceleration will be very difficult (Savinainen and Viiri, 2008).

Mualem and Eylon (2010) claim that students in junior high schools struggle to apply their knowledge and predict phenomena because multi-step reasoning is required to do this and students often do not have the problem-solving strategies that they need to do this. Real world problems usually require students to recognise and apply multiple concepts simultaneously, often from across the physics curriculum, which is difficult (Badeau et al., 2017).

It is widely acknowledged that force and motion concepts are challenging to teach effectively (McDermott, 2001; Singh, 2007; Singh and Schunn, 2009). These physics topics are conceptually pivotal, but difficult to learn and are entangled with many misconceptions, which are difficult to unravel, possibly because the Newtonian view of force is constantly challenged by students' everyday experiences, entrenching their preconceptions (Halloun and Hestenes, 1985; Singh and Schunn, 2009). Our interaction with Newtonian mechanics is largely only as a mental model, making it cognitively challenging (Nersessian, 1989), particularly as students are unable to transfer their understanding to other representations (Greeno, 1989). Students tend to apply pre-Newtonian physics, such as the view held by Aristotle that objects will be at rest in the absence of a force (Lombardi, 1999; Atasoy and Ergin, 2017).

2.4 Student characteristics that affect learning

Developing conceptual understanding requires cognitive and processing skills. Problem-solving requires its own set of skills, which are developed through engagement with appropriate material. When presented with a problem, students are usually presented with a problem text. This has to be translated into a problem representation, which leads to a sequence of actions to solve the problem (Greeno and Johnson, 1985). These translations or transitions require an understanding of the following: the words and their meaning (linguistic competency); an understanding of the actions and the relations between those actions; an understanding of the conditions under which these actions are appropriate (operational competence), as well as conceptual and procedural competence (Greeno and Johnson, 1985). This means that students require a broad range of skills to master problem-solving, but two distinct factors have been found to play a significant role in the development of problem-solving skill.

2.4.1 Mathematical competency:

Mathematical knowledge and competency is needed to describe and understand physical systems and solve physics problems (Angell et al., 2004; Redish and Kuo, 2015). Meltzer (2002) found a correlation between mathematical skill and the learning gain in physics, indicating that low mathematical skill can be an obstacle to learning physics. The skill of logical reasoning is important in mathematics and the level of this skill may affect student's performance in physics (Meltzer, 2002).

2.4.2 *Attitude:*

Cahill et al. (2018) reported a correlation between learning gains on the Force Concept Inventory (FCI) over the duration of a physics course and the incoming attitudes of the students. They attributed this to the effort that is required to develop coherent conceptual models of abstract concepts. Students would require a positive attitude in order to put in the required effort (Cahill et al., 2018). Students who relish the challenge that learning provides and recognise that it requires strategic practice and effort show greater resilience and higher achievement (Blackwell, Trzesniewski and Dweck, 2007; Schell and Butler, 2018; Yeager and Dweck, 2012). Improvements in performance have been shown in courses where there is an emphasis on changing students' approach to physics (Madsen, McKagan and Sayre, 2015).

2.5 Possible solutions: What's been tried

The literature pertaining to Physics Educational Research reveals the extent and depth of research that is being done to improve teaching and learning in physics. Meltzer and Otero (2015, p. 455) write about a "deep concern for improving access to and understanding of the principles and process of physics", which conveys the spirit of this research. Physics education researchers want to help students to develop a better understanding. They do not want to present neatly-packaged 'knowledge', but rather to enable students to successfully acquire the skills and concepts that they need.

Experts have not always been experts and do not always solve problems optimally. However, they have been able to automate many of their problem-solving processes through years of experience. Rather than expecting novice problem-solvers to perform as experts, we should aim to teach students methods and procedures that will produce more expert-like problem-solving behaviour (Heller and Reif, 1984).

Diverse approaches to help students deepen their engagement and construct knowledge have been tried and tested. These approaches have similarities and most are embedded in one or more of the learning theories outlined in Section 2.2. Some of these are goals of teaching, while other are instructional approaches. Some approaches are used in isolation and some together.

This section discusses the overarching ideas of constructing knowledge structures and active learning and then summarises some approaches from literature that focus on improving teaching and learning in physics. The emphasis in this review is on *learning* physics, rather than *teaching* physics. The approaches are loosely grouped as those advocating structure, the use of representations and metacognition. There is much overlap between the groups and the links between the approaches. The learning theories will be reinforced in the discussion of results in Chapter 4.

2.5.1 Constructing knowledge structures

A person who is acquiring new information or knowledge is gathering – or storing – building blocks of knowledge (schemas) as they produce a mental representation of the knowledge. These schemas need to be retrievable to be useful and so an internal knowledge structure needs to be constructed to retain concepts for rapid, flexible and reliable retrieval from memory (Reif, 1983; Singh, 2004). Novices store small pockets of knowledge and facts as discrete and often unrelated information, while more expert students store larger 'chunks' of knowledge and establish the connections and patterns between concepts and the relations between structures and variables (Cahill et al., 2018; Reif, 1978).

Traditional teaching approaches have been under increasing criticism in recent years. They are criticised for not helping students to construct a 'coherent framework' for their knowledge (McDermott, 1993). Different methods of instruction may vary in their effectiveness to produce internal knowledge structures (Eylon and Reif, 1984). Making the links between new concepts and familiar knowledge explicit will allow students to connect new knowledge to previously acquired knowledge (Cahill et al., 2018). Reif (1983) maintains that the skill of ordering knowledge can be developed and that students could be taught to improve their skill at learning new concepts independently.

A related, but rarely mentioned approach, is concept mapping. Concept-mapping techniques require students to represent their knowledge of concepts and the relationships and links between them. This provides insight into their understanding and gives a picture of their cognitive structure to instructors (van Gog et al., 2009), while helping students to make the connections and patterns explicit, which might help them create a coherent knowledge structure.

2.5.2 *Active learning*

Schell and Butler (2018, p. 2) define active learning as “a process whereby learners deliberately take control of their own learning and construct knowledge rather than passively receiving it”. This constructivist approach to learning has gained popularity in the last 50 years and is widely adopted by physics education researchers globally.

McDermott (1993) claims that intellectual engagement and active learning are essential for a significant conceptual change and learning to occur. Students in classes where active learning methods are used and conceptual understanding is emphasized, out-perform students in classes where traditional lecture-style teaching occurs (Hake, 1998; Van Heuvelen, 1991b; Mazur, 1995). Active learning assists students to integrate new information with existing knowledge to produce a robust cognitive structure (Egan and Greeno, 1973; Schell and Butler, 2018). Gautreau and Novemsky (1997, p. 425), who showed the benefit of students working in small groups, write that “There are many assumptions made in the traditional teaching process that simply do not induce learning.”

Most of the approaches that follow are examples of active learning, where students are engaged and involved in their learning, rather than passive observers.

2.5.3 *Structured problem-solving*

Problem-solving is the approach to an unfamiliar or novel situation to achieve a particular outcome or reach a goal. Often this deliberate process will require planning or a sequence of steps (Singh, 2004), particularly as the complexity of the problems increase, or when problems are content-rich (Huffman, 1997; Singh, 2004). Reif (1978) believed that science education needed to develop not only a well-organised base of knowledge for problem-solving, but also a systematic approach to retrieve and apply that knowledge. Mualem and Eylon (2010) argue that the level of problem-solving that physics requires, does not follow directly from understanding concepts, and that a strategy is needed to solve problems to help bridge the gap between these concepts and the ability to use them.

This systematic approach is intuitive for some and experts typically have a more strategic approach to problem-solving, usually beginning with a plan or with the overall structure in mind (Singh, 2004). Novice problem-solvers have a more discrete view of concepts and may benefit from explicit guidance to implement a systematic approach (Singh, 2004; Lin and Singh, 2015). This is particularly useful when students need help in recognising conflict in their conceptual understanding and restructuring their misconceptions (Lin and Singh, 2015).

Huffman (1997) designed a study to test whether teaching an explicit five-step problem-solving strategy improved problem-solving performance and conceptual understanding. He found that the strategy did not help the students' planning and mathematical execution in problem-solving or their conceptual understanding, but improved the quality and completeness of their physics representations (more on these in Section 2.5.7). This was because the strategy tested required the student to develop their representation to progressively more abstract and mathematical domains in each step of the strategy (Huffman, 1997).

Gaigher, Rogan and Braun (2007) modelled their study on Huffman's, working in a South African context. Students were taught to use a very specific series of steps to solve physics problems throughout the year, which were designed to develop conceptual understanding. The students showed improved test and examination results compared to the control group who were not taught to use the structured problem-solving method. Gaigher et al. (2007) attributed the success of the intervention to the forced exposure of the students to the translations between the domains suggested by Greeno (1989) (Gaigher, Rogan and Braun, 2007). The problem-solving steps prompt students to perform these translations, providing multiple ways to understand physics and to strengthen the links between the domains (Gaigher, Rogan and Braun, 2007).

Mualem and Eylon (2010) point out that one of the drawbacks of encouraging a problem-solving strategy is that students do not continue to use the strategies on their own when they are not instructed to. However, Rosengrant, Van Heuvelen and Etkina (2009) found that if students learn physics in a course that emphasises the use of free-body diagrams or multiple representations (see Section 2.5.7.2), they will use them to solve problems.

There are two points of caution regarding problem-solving strategies. Hewitt (1993) writes that in high school, particularly, the focus on teaching problem-solving often obscures the students' understanding of concepts. Hewitt (1993), as well as Huffman (1997) suggest that the time and effort spent on teaching problem-solving would be better spent on concepts and fundamental principles. In addition, Kuo, Hallinen and Conlin (2017, p. 831) pose the question "how can we teach routines without making thinking routine?" They caution that teaching problem-solving procedures could dampen the adaptive problem-solving that we expect from students later on. So, in order to get students to show mastery in an assessment, we need to guard against expecting them to limit their problem-solving approaches to those taught, since we expect them to show creative and innovative problem-solving strategies in other contexts.

2.5.4 Model Instruction

The term ‘model’ has already been used in a different sense in Section 2.2.1 to refer to a model representation. In the present context, models, or conceptual models, are abstractions of objects, processes or events that scientists use to make observations, identify patterns in data and then develop and test explanations for those patterns (Hubber and Tytler, 2013). Examples of conceptual models in this context include mathematical models (e.g. $F_{net} = ma$), pictorial models (e.g. free-body diagrams), gestural models (e.g. Fleming’s left hand rule) and textual models (e.g. Newton’s second law) (Tay and Yeo, 2017).

The models constructed by students are limited to their exposure to examples and situations. Early in physics instruction, they may, for example, only be equipped to deal with situations without friction or without taking into account the gravitational force of the Earth (Mualem and Eylon, 2010). Students are required to refine and upgrade these models as they encounter more complex examples. Eventually their mental models are sufficiently refined and robust to be applied to any problem (Mualem and Eylon, 2010).

In the 1970’s, Lillian McDermott devised a ‘guided inquiry approach’ to constructing a model that equips students to explain and predict phenomena (McDermott, 1976). Such an approach engages students in generating, evaluating and modifying models (Hubber and Tytler, 2013). An improvement in expert-like thinking and problem-solving has been shown in classes where there was an explicit focus on model-building (Madsen, McKagan and Sayre, 2015).

2.5.5 *Peer interaction*

Eric Mazur was the champion of peer interaction, pioneering it in the mid-1990's at an American university when he noticed that despite his best efforts, there was little improvement in his students' conceptual understanding through the physics course (Mazur, 1995). He devised a carefully-planned programme of pre-class tasks, lectures and conceptual tests (called ConcepTests). The tasks are scaffolded and there are many diverse opportunities for feedback and explanation, all of which aim to deepen understanding (Schell and Butler, 2018).

Peer instruction promotes student engagement in active learning and has been shown to improve student performance (Schell and Butler, 2018). Students are able to learn and evaluate effective problem-solving strategies through reflection with their peers and, even with minimal guidance from instructors, this peer interaction is found to be beneficial (Mason and Singh, 2016b). The approach uses the coaching and scaffolding stages of the cognitive apprenticeship model, which are often thought to be neglected in conventional teaching, so fills a perceived gap (Mason and Singh, 2016b). It also relies on the principles of conceptual change as students interrogate their understanding of concepts and reach accommodation.

Peer interaction helps students to develop their understanding of scientific concepts as they are required to articulate and discuss their solutions and debate which solution is correct or most effective (Mason and Singh, 2016b). It also requires a high level of cognitive processing which promotes learning and as such has been shown to improve the scores of students in conventional assessments (Mason and Singh, 2016b).

Peer instruction, as formulated by Mazur (1995), has been shown to be successful in improving learning. The resource has been field-tested and researched. Others have tried to replicate his model with changes, but it has been cautioned that when modifications are made to an instructional model without careful research, these changes might inhibit or limit the success of the intervention by reducing active learning (Schell and Butler, 2018). A further caution by Mazur (1995) is that with the focus on conceptual understanding, the skill of problem-solving could be ignored during peer interaction.

2.5.6 *Use of Self-Paced Learning Tutorials*

In the absence of peers, students can be encouraged to engage with concepts and construct connections by asking them questions or asking them to mentally model or reason (Kuo, Hallinen and Conlin, 2017; Marshman, DeVore and Singh, 2018; Singh, 2008c). Such tasks are often designed to be worked through independently and may be set as 'warm-up' exercises, which are intended to be done independently and prior to learning tutorials (Singh, 2008c). This is particularly useful to review prior knowledge to ensure maximum benefit from contact time with an expert (Marshman, DeVore and Singh, 2018). There may also be motivational benefits to a pre-test, which identifies the concepts that students do not fully understand – or those that they completely misunderstand – which could incentivise students to fully engage with the learning tutorial with the intention of mastering the concepts, as well as flagging these concepts for the instructor (Singh, 2008c).

Many learning tutorials make use of available technology (Singh, 2004) and there is extensive opportunity for innovation in this approach. One of the significant outcomes of such a resource, in addition to the physics-related outcomes, is self-reliance. However, motivation and student buy-in are important for the use of an independent learning tutorial to be beneficial (Marshman, DeVore and Singh, 2018), particularly if guidance is 'weaned' or reduced over time. It is also important that the difficulty of the problems is gauged from the student's perspective so that they are accessible and useful (Singh, 2009).

2.5.7 *Representations:*

When we solve problems, we use internal representations, which are created in our minds, and external representations, which are drawn or written on paper or a board (Larkin and Simon, 1987). Physics is a representation-rich subject, making use of diagrams, pictures and graphs to clarify, explain, depict and solve problems.

2.5.7.1 Diagrams

Van Heuvelen (1991a) writes that a diagram provides an uncluttered summary of the key points relating to a physics problem. It provides a means to organise and group relevant information together so that it is available for problem-solving, in a form that allows us to infer much about the situation and visualise it (Larkin and Simon, 1987; Mason et al., 2008; Scheiter, Schleinschok and Ainsworth, 2017; Van Meter and Garner, 2005). Diagrams can also be combined or sequenced to describe a more complex process and a diagram can be used to construct a detailed mathematical representation (Van Heuvelen, 1991a).

Experts tend to use a variety of different representations as a first step in their problem-solving process and change effortlessly between them, choosing the most convenient, applicable representation for each problem, while novices have a tendency to jump straight to a mathematical representation, such as a formula (Kohl, Rosengrant and Finkelstein, 2007; Maries and Singh, 2017; Singh, 2004). This initial translation of the verbal description of the problem to a representation that is more suitable for analysis, helps to make relevant information explicit and available with less processing to extract it (Larkin and Simon, 1987; Maries and Singh, 2017; Scheiter, Schleinschok and Ainsworth, 2017). However, while experts faced with a problem immediately choose an appropriate and useful representation, novices do not use the most effective representation when they approach a problem (Rosengrant, Van Heuvelen and Etkina, 2009).

The task of drawing assists the processing of verbal information and transferring it into non-verbal representations, which forces deeper engagement and organisation of information (Van Meter and Garner, 2005). The effort required for this process of translation may improve learning yield (Scheiter, Schleinschok and Ainsworth, 2017). In the generation of a diagram, a mental image is created and this can be considered ‘dual coding’, which is a combination of images and verbal information, which improves processing skills (Kruger, 2013). Dual coding of information increases the likelihood of retrieval from memory (Scheiter, Schleinschok and Ainsworth, 2017).

Drawing a diagram also assists with reducing cognitive load, as the information is visible and no longer needs to be held in the working memory (Maries and Singh, 2017, 2013). The paper then becomes an extension of the problem-solver’s working memory capacity (Larkin et al., 1980).

Drawing diagrams certainly aids problem-solving and a positive correlation has been found between performance in assessment and drawing more diagrams (Mason and Singh, 2016b), even if students are not rewarded for drawing diagrams (Maries and Singh, 2017). As a result, many introductory physics courses encourage students to make use of this problem-solving heuristic (Maries and Singh, 2017, 2013).

The quality of the diagram produced affects its usefulness. A ‘productive diagram’ is one in which information is well-organised and arranged or visualised in such a way as to help the problem-solver (Larkin and Simon, 1987; Maries and Singh, 2017). A correlation has been shown between the detail in a diagram and problem-solving performance, with students who drew diagrams with the highest level of relevant detail performing nearly twice as well as those students who drew ‘unproductive’ diagrams (Maries and Singh, 2017, 2013).

When considering free-body diagrams rather than schematic diagrams, it has been found that only drawing correct free-body diagrams improved students' score (Maries and Singh, 2018).

Despite the benefits, students seem to resist drawing diagrams or do not appreciate the value of a diagram (Larkin and Simon, 1987; Van Heuvelen, 1991a). This is thought to be because they do not understand or are unable to interpret the meaning of the concepts and quantities in the diagram (Van Heuvelen, 1991a). If they are unable to use diagrams effectively – or even at all – they may well not appreciate the value of the diagrams and find them largely useless (Larkin and Simon, 1987). They may also be unable to construct their own diagrams, as they have had little practice in doing so, having been largely passive observers as the expert presented knowledge and constructed diagrams (Van Heuvelen, 1991a).

Prompting students to draw a free-body diagram in introductory mechanics courses has been found to encourage them to use problem-solving methods (rather than intuitive methods that may lead to an incorrect approach), which results in better performance (Heckler, 2009; Maries and Singh, 2013). Students who were prompted to draw a diagram were also more likely to draw expert-like diagrams (Maries and Singh, 2017) and students who drew more expert-like diagrams were more successful problem-solvers (Maries and Singh, 2013), suggesting that prompting students to draw diagrams improves problem-solving. Students should be prompted to draw a diagram in scaffolded problem-solving strategies and should also be guided to include as much relevant information as necessary, to promote more efficient and more effective problem-solving (Maries and Singh, 2017).

In contrast, Heckler (2009) found that when students were prompted to draw a force diagram they were less likely to obtain a correct solution compared to those who chose their own approach, possibly because they might not use a formal problem-solving approach as successfully as a more intuitive approach.

Weaker students struggle to draw diagrams and, if prompted to draw a free-body diagram, are hampered by their difficulty with this task (Heckler, 2009).

Some research has been done on the impact of providing a diagram in a question. It seems that not providing a diagram encourages students to draw their own. Drawing their own diagram promotes ‘deep processing’, which deepens understanding, whereas looking at a given diagram results in only shallow processing (Chen et al., 2017). In a study where students were either given a diagram or instructed to draw one, Maries and Singh (2018) found those who were given a diagram performed worse than those who drew their own. The reason for this emerged when the students were interviewed: those who were provided with a diagram spent less time analysing the problem and planning their approach and dived straight into the execution of a hurried problem-solving strategy, which increased the likelihood of error. When a student draws a diagram, their problem-solving process is improved, so not supplying a diagram with a question is beneficial, as students are more likely to draw their own, improving problem-solving performance, as well as, in a teaching setting, problem-solving strategy. However, there is a place for providing diagrams when the physical context of the problem may be unfamiliar to students or when clarity on the physical situation is required (Chen et al., 2017).

2.5.7.2 Multiple representations

Diagrams are not the only representations that are used in physics, and students should be able to recognise and manipulate a concept in a variety of representations (Van Heuvelen, 1991a). We are often unable to recognise information and retrieve it from long-term memory if it does not match the representation that is given (Larkin and Simon, 1987). An example that Larkin and Simon (1987) used to explain this disparity, is that of the Serbian and Croatian languages. When spoken, they are no more different than the British and American dialects of English. However, the Serbian language uses the Cyrillic alphabet, while Croatian uses the Roman alphabet. When written, they are poles apart and someone fluent in one language would find it difficult to read the other. In the context of a physics problem, students may understand a problem in one representation or see similarities between problems when they are explained, but when presented with a problem in another representation, might not recognise it.

More expert-like thinking is developed, and understanding and problem-solving are greatly enhanced, if students are able to translate back and forth between different representations and make use of multiple representations (Rosengrant, Van Heuvelen and Etkina, 2009; Van Heuvelen, 1991a; Van Heuvelen and Zou, 2001). This is a goal of many teaching courses:

> "…one objective of our instruction is to help students learn to (1) construct qualitative representations of physical processes and problems, (2) reason about the processes using these qualitative representations, (3) construct mathematical representations with the help of the qualitative representations, and (4) solve the problem qualitatively. Students are learning to think like physicists." *(Van Heuvelen, 1991a, p. 892)*

Kohl and Finkelstein (2006) tested students with problems that were essentially isomorphic, but presented in different representational formats. They found that in many cases the student's approach or strategy choice was guided by the surface features of the problems. Even students in this study who were then exposed to – and expected to use – a greater variety of representations, struggled to choose the most appropriate representation (Kohl and Finkelstein, 2006).

A representation-rich learning environment should be developed with activities that familiarise students with a variety of representations and help them to learn when and how to use them appropriately (Kohl and Finkelstein, 2006;

Rosengrant, Van Heuvelen and Etkina, 2009). Van Heuvelen (1991b) developed an introductory university physics course, 'Overview, Case Study Physics', intended to develop problem-solving competency based on qualitative understanding, through the use of representations. In this course, the instructors use a variety of representations in their explanations and the students then use these representations in their problem-solving. The lectures, based on 'Overview, Case Study Physics', were to be supplemented or accompanied by Active Learning Problem Sheets, which have students answering questions and solving problems with neighbouring students before receiving feedback from the presenter of the course (the 'expert') (Van Heuvelen, 1991a). This intervention has shown to benefit student understanding (Van Heuvelen, 1991b; Gautreau and Novemsky, 1997).

Kohl, Rosengrant and Finkelstein (2007) compared a student body who were explicitly taught a problem-solving strategy using a multi-representation approach to those for whom multiple representations and problem-solving strategy was modelled, but not specifically taught. Students in both courses were able to successfully use multiple representations across a variety of problems.

Mualem and Eylon (2010) investigated how a problem-solving strategy in junior high school could use visual representations that are easily understood to guide students from characterising the system in terms of interactions to drawing a free-body diagram. Students were better able to explain physics observations and concepts after using this strategy and retained their knowledge for at least six months.

2.5.8 Worked examples

A worked example is a problem that is presented with a set of steps toward the solution, modelling an expert-like strategy or approach (Badeau et al., 2017). Studying worked examples has been found to be an effective way to learn new problem-solving skills (Chi et al., 1994; Hoogerheide et al., 2019).

Worked examples may promote learning and understanding more effectively than actual problem-solving (Smith, Mestre and Ross, 2010). This is partly because students spend considerable time trying incorrect problem-solving strategies, while worked examples hold the same instructional benefit without the inefficient use of time (Smith, Mestre and Ross, 2010; van Gog, Paas and Sweller, 2010). Students have also been shown to retain only a small proportion of conceptual information when they read text in a question, possibly because they focus on problem-solving at the expense of conceptual understanding (Smith, Mestre and Ross, 2010). When studying a worked example, they are able to focus their cognitive resources on building conceptual schema, rather than devoting resources to solving the problem (van Gog, Paas and Sweller, 2010). Worked examples also offer the opportunity for the provision of additional information and opportunities for students to self-explain the steps and the connections between steps (Smith, Mestre and Ross, 2010).

Students are sometimes able to solve problems, but do not build a conceptual understanding through the process. Sweller's (1988) idea was that limited cognitive resources are allocated to schema acquisition during problem-solving when the cognitive load is high. There is insufficient capacity in the working memory for schema acquisition to occur when the load is high. Particularly when learning new concepts, the cognitive load associated with working through a worked example is much lower than for an equivalent problem, allowing schema to be constructed (Sweller and Chandler, 1991). The use of worked examples can reduce cognitive load initially and, as more processes become familiar and automated, and more schema have been developed and are available, students can progress to problem-solving with more working memory available (Paas, Renkl and Sweller, 2003)]

Worked example steps can be faded out to move students towards independent problem-solving (Paas, Renkl and Sweller, 2004). They begin with detailed instructions and deliberate examples when only a few schemas are available (e.g. when a new topic is introduced), as the intrinsic cognitive load is high. As schemas are acquired, students could study worked examples with few prompts and instructions and use their own self-explanations, before attempting independent problem-solving, once sufficient schema have been acquired (Paas, Renkl and Sweller, 2003).

The extent of impact of transfer from worked examples is influenced by the ability of students (Paas, 1992; Chi et al., 1989). More able students are able to read worked examples with understanding and make connections between the steps shown, self-explaining (Section 2.5.9) and self-diagnosing (Section 2.5.10) as they read (Chi et al., 1989). Students who struggle often fail to make the connections between their understanding and the text and, if they detect a mismatch between their understanding and the worked example, it is only with regard to mathematical manipulations, rather than underlying conceptual problems (Chi et al., 1989).

There may be value in watching an expert solve a problem (either in real life or on video) while they verbalise their thoughts and their reasons for each step (van Gog et al., 2009). However, the experts must be conscious of their audience and of their level of conceptual understanding as many processes are automated in expert thinking and problem-solving approach, which may detract from the value of this exercise for modelling purposes (van Gog et al., 2009).

Teaching the content of a worked example to a fictitious peer on video camera has also been found to enhance the positive effect of studying a worked example because of the cognitive process of articulating an explanation. This encourages students to engage deeply with the example and provides the opportunity to expose and repair any conceptual problems and to structure their knowledge coherently (Hoogerheide et al., 2019). As this is tending to self-explanation, worked examples are often coupled with self-explanation. In fact, Chi et al. (1989) believe that the effectiveness of worked examples for learning depends on self-explanation.

2.5.9 Self Explanation

Students who work through a task in a think-aloud setting have been found to engage more effectively with the task as asking them to explain their thinking deepens their engagement (DeVore, Marshman and Singh, 2017; McDermott, 1991). Students who are intellectually engaged in the learning process stand to learn more (McDermott, 1991; Singh, 2009). Maries and Singh (2018) found that when they asked students to work through examples thinking aloud, these students learned more from the task than those who did not self-explain through the think aloud process.

Self-explanations can assist students to create inference rules (Chi et al., 1989) and to integrate newly acquired information into their existing knowledge structure (Chi et al., 1994). Prompts that encourage students to identify key principles and processes and guide students to better quality self-explanation, enhance the value of this learning approach and improves transfer (van Gog et al., 2009). Students who generate better quality self-explanations perform significantly better on follow-up tasks as they learn more from the activity (Chi et al., 1989; van Gog et al., 2009). Even fragmented or incorrect self-explanations help students to gain more than those who do not self-explain (Lin and Singh, 2011).

More proficient students are better able to self-explain, making links and expanding or refining the conditions of the examples, while students who struggle do not self-explain (Chi et al., 1989). Students whose knowledge is insufficient for the task, experience high cognitive load which can hinder learning, unlike those who are able to articulate their understanding and gain from the task of self-explanation (van Gog et al., 2009). As learning gains depend on the quality of self-explanation, supporting students towards better self-explanations is beneficial (Yerushalmi et al., 2008).

2.5.10 Self-diagnosis

In this approach students are presented with their test solutions and asked to identify where they went wrong and to explain their mistakes. When students retrieve information and use it, they are able to assess their understanding and determine any shortfalls in their knowledge (Schell and Butler, 2018).

Self-diagnosis can be encouraged through a structured evaluation of the student's solution (Yerushalmi et al., 2009). It tests students' use and application of physics principles as well as their presentation of a strategic problem-solving approach (Cohen et al., 2008).

Helping students to look back at the problem-solving process and think about what they learnt in solving the problem and how this has adjusted their thinking and helped them to organise their knowledge helps them to develop meta-cognitive skills (Singh, 2004). Prompting self-diagnosis fosters reflective and diagnostic habits which assist students to learn from their mistakes (Mason et al., 2009; Yerushalmi et al., 2008; Schell and Butler, 2018). However, it seems that students are not easily able to transfer the skills and lessons learnt from evaluating an incorrect solution to similar problems (Cohen et al., 2008; Yerushalmi et al., 2009).

Once again, as with self-explanation and the use of representations, the quality of the self-diagnosis determines the learning gain. Often low achievers are unable to self-diagnose without specific guidance, and their ability to reflect on their method, diagnose errors and conceptual inconsistencies and learn from them, is limited (Mason et al., 2009). Mason et al. (2009) propose that too much support may lead to superficial self-diagnosis which does not lead to meaningful integration of knowledge or successful repair and transfer.

2.5.11 Isomorphic Problem Pairs and Analogical Comparison

Isomorphic problem pairs (IPPs) are often used to help students recognise the 'deep' concepts embedded in a problem: the physics principles that an expert would recognise when looking at a problem, while the novice sees the surface features such as context or physical components. Studying IPPs with sufficient scaffolding, focussing on their similarities and differences, can assist in useful generalisations and the acquisition of schema (Badeau et al., 2017; Lin et al., 2010). This may also provide an opportunity to combat misconceptions, but the scaffolding needs to be sufficient, explicit and tested for maximum learning and transfer (Lin and Singh, 2015, 2011).

Sometimes a quantitative problem is paired with a question that requires qualitative reasoning. Students perform better on the qualitative problem when presented with the quantitative problem first, as they can use the quantitative reasoning to guide them when answering the more conceptual problem (Singh, 2008a).

Analogous comparison can be made between IPPs, where students are presented with a solved problem and given an analogous or isomorphic problem to solve. It uses the knowledge that the student already has in place to bridge to new knowledge, often using the structure or problem-solving approach from a worked example (Badeau et al., 2017). Solving IPPs may improve a student's metacognitive skills as they consider their problem-solving process, particularly when this is made explicit (Singh, 2008a).

Studying IPPs may encourage students to identify 'deep' concepts and then to look for them elsewhere (Lin and Singh, 2011). As identifying these underlying physics principles is an expert approach, fostering this skill will help guide students to more expert-like behaviour. Singh (2008a) suggests rewarding students for recognising isomorphic problems in exercises to encourage them to look for and to learn to recognise isomorphic problems. She believes that this may foster a habit of analysing the concepts relevant to a question before jumping into mathematical processes.

2.5.12 Categorisation

The ability to categorise a problem according to its relevant physics may be the factor that differentiates experts from novice problem solvers (Chi, Feltovich and Glaser, 1981; Mason and Singh, 2016a; Sweller, Mawer and Ward, 1983). Chi, Feltovich and Glaser (1981) conducted a seminal study in which they gave cards with physics problems printed on them, to experienced academics and introductory students. The people were instructed to sort the cards into categories. They (and subsequent researchers) found that the experts tended to categorise physics problems based on how they should be solved. Novices based their classification on superficial characteristics, often based on appearance, such as whether an object was on an incline or not, rather than on the applicable laws and principles underlying the problem (Chi, Feltovich and Glaser, 1981; Maloney, 2011; Sweller, 1988).

Mason and Singh (2016a) suggest that a categorisation task is particularly effective when performed in small, mixed-ability groups where discussion and debate is generated around the reasons for categorisation, leading to valuable learning. The classification of problems is an important step in schema acquisition (Sweller and Chandler, 1991) and it prompts the often-neglected step in problem-solving of conceptual analysis of a problem statement (Chi, Feltovich and Glaser, 1981; Mason and Singh, 2016a). A student's categorization of problems can also provide insight for teachers into their understanding and perceptions (Mason and Singh, 2016a).

2.5.13 Strategies for Engaged Learning Framework (SELF)

Strategies for Engaged Learning Framework (SELF) is a framework that was proposed by DeVore, Marshman and Singh (2017) to assist in the development of learning tools that can be beneficial to students from diverse backgrounds. The framework considers the learning tool, environmental and social factors, as well as student characteristics, to design an effective learning tool (Marshman, DeVore and Singh, 2018). Internal and external characteristics of both the user and the self-study tool are considered and these can be seen in Table 2.3. The consideration of the external factors increases the chances that a learning tool is appropriate for the context in which it is used and will be adopted. Personalised learning tools can supplement learning or provide support outside the classroom. Self-paced learning tools that are carefully crafted and scaffolded can assist students from a wide range of prior abilities and levels of preparation, through support and feedback. However, student buy-in is important and explaining the importance of the learning activity may help to make it personally meaningful (Marshman, DeVore and Singh, 2018).

Table 2.3: *The Strategies for Engaged Learning Framework (SELF) (DeVore, Marshman and Singh, 2017, p. 11).*

Factors that promote self-regulated learning		
	Tool characteristics ↔	User characteristics

Internal characteristics	Factor I: Self-study tool characteristics (internal) – pertaining to how the tool focuses on knowledge / skills to be learned
	• Develop adaptive tools based on "cognitive apprenticeship model" to promote mastery of material for a variety of students
	• Include material providing scaffolding support
	• Focus on developing adaptive expertise
	• Incorporate elements of productive engagement and productive struggle
	• Involve formative assessment
		Factor II: User characteristics (internal)
		• Prior knowledge
		  ○ Prior preparation
		  ○ Goals
		  ○ Motivation to learn
		  ○ Cognitive / metacognitive skills
		• Self-efficacy and other affective characteristics
		• Epistemological beliefs

↕ External characteristics	Factor III: Self-study tool characteristics (external) – pertaining to how the self-study tool is implemented effective usage of self-study tools
	• Embed features to frame the importance of learning from self-study tools and to get student buy-in
	• Embed motivational features within self-study tools conducive to effective learning
	• Reinforce learning by coupling learning of different students via creation of learning communities
	• Make explicit connection between self-paced learning and other in-class lessons or out of class assignments and assessments
	• Incentivize students to engage with self-study tools via grades and other motivational factors
	• Support to help students manage their time better
	• Support to improve students' self-efficacy and epistemological beliefs
		Factor IV: User characteristics (external) – pertaining to the user-environmental interaction
		• Self-management
		  ○ Minimizing unimportant activities that appear urgent (e.g., socializing)
		  ○ Maximizing important activities that may not appear to be urgent (e.g., working on a self-paced learning tool)
		• Balancing coursework and / or work
		• Family encouragement and support
		• Support and mentoring from advisors and counsellors

2.6 Development of task

When designing an effective task or instruction activity to aid learning, it is important to consider the processes that are involved in understanding and solving problems, as well as the prior knowledge required to complete the task (Greeno et al., 1986; Reif and Heller, 1982). Teachers or designers of instruction need to know and understand the students' problem-solving performance, where they need to be and how to make the transition (Reif, 1978; Reif and Heller, 1982).

A structured approach of packaging learning into organised components, assists in automating learning and can reduce intrinsic cognitive load, freeing the working memory capacity for assimilating schema (Paas, Renkl and Sweller, 2003). This supports the need for a resource with scaffolded worked examples, which are sequenced from simple to complex in order to reduce the intrinsic load and assist in the acquisition of schema (Paas, Renkl and Sweller, 2003). Such a resource should encourage the construction and automation of schema (Paas, Renkl and Sweller, 2004).

This resource could also 'model' sound problem-solving approaches, as advocated by the theory of cognitive apprenticeship (Collins et al, 1987), including drawing diagrams. Worked examples could be annotated to coach students to better understanding and to assist with categorisation by drawing attention to physics principles. Although this coaching is generic and not specific to a particular student, it can be tailored to fit the most common misconceptions and errors. The examples should be a series of progressively more complex examples ('scaffolding' (Collins et al, 1987)), followed by a revision worksheet ('weaning' (Collins et al, 1987)).

Categorisation of examples and presenting students with isomorphic problem pairs also helps to build schema and assists students in connecting new information to existing knowledge. This is because such processes assist students in seeing the similarities in the physics between different examples and encourages them to interpret a problem beyond its surface characteristics.

Once many schema are automated, students are able to engage in more metacognitive processes, such as self-explanations and self-diagnosis. This is impossible when significant cognitive load is being used on the task of problem-solving, but once this load is reduced, students are able to think about what they are doing as they are doing it. This allows for refinements and categorisation.

It is important that language is accessible, to reduce the demand on space in working memory (Johnstone, 2009). The task should also ensure that students have the necessary prior knowledge and mathematical skills on which to build new knowledge and engage with physics content, without excessive cognitive load putting the task beyond the student's grasp (Johnstone, 2009; Singh and Schunn, 2009).

Rosenblatt, Heckler and Flores (2013) suggest that a process of designing, testing, refining and retesting instructional tasks or tutorials can improve students' understanding of physics. The development a tutorial involves three steps: identify the content topic and the goals of the task; identify and characterise the difficulties that students have with this content or topic; design and produce material that is intended to address these difficulties (Rosenblatt, Heckler and Flores, 2013).

Conceptual change requires a disconnect or dissonance to be identified for accommodation and assimilation to occur. Kural and Kocakülah (2016) assert that the teacher needs to identify preconceptions of the students during teaching so that these can be corrected through accommodation. So, the resource material should elicit the difficulties that the students have and provide opportunity to confront their difficulties before engaging them in activities to resolve their difficulties (Rosenblatt, Heckler and Flores, 2013). These activities need to be appropriate to build understanding (Scheiter, Schleinschok and Ainsworth, 2017).

However, in the case of a resource designed to be used independently by students, there is no teacher to perform this role. The bridge between previous knowledge and new knowledge can be constructed through structured worked examples encouraging self-diagnosis. The learning cycle mirrors Action Research in that a problem is encountered, confronted and then worked through until it makes sense or resonates with the existing prior knowledge, so that new information can be assimilated.

In summary, some design principles for a targeted learning intervention can be drawn from the literature reviewed:

- Material needs to assist learners to construct a coherent framework for their knowledge (McDermott, 1993) by
    - making explicit links between new concepts and familiar knowledge (Cahill et al., 2018)
    - developing the skill of ordering knowledge (Reif, 1983)
    - establishing the relations between the representations of a problem or situation (Greeno, 1989)
    - modelling strategies such as concept mapping.

- Active learning and intellectual engagement are necessary for significant conceptual change (McDermott, 1993), which could be encouraged through
    - requiring students to draw diagrams (Chen et al., 2017)
    - self-explanation (DeVore, Marshman and Singh, 2017; McDermott, 1991)
    - self-diagnosis (Yerushalmi et al., 2008).

- A carefully structured resource, which is organised into components, reduces cognitive load, allowing for the acquisition of schema (Paas, Renkl and Sweller, 2003). The resource should:
  - begin with simple examples before progressing steadily in complexity, to reduce cognitive load and assist in schema acquisition (Sweller and Chandler, 1991)
  - *model* a systematic problem-solving approach (cognitive apprenticeship (Collins, Brown and Newman, 1987)) to prompt novice problem-solvers to adopt a more expert-like approach
  - include annotated worked examples to *coach* students to better understanding and problem-solving (Collins, Brown and Newman, 1987)
  - *scaffold* learning with progressively more complex examples, followed by a revision worksheet that allows students to solve problems with less guidance (*weaning* (Collins, Brown and Newman, 1987))
  - include isomorphic problem pairs to assist in categorisation of problems and building schema (Sweller and Chandler, 1991).

The task of developing the resource should be iterative, tested and refined as it is developed and cannot be expected to meet its goals after only one implementation. This iterative process is well-described by the action research methodology and this was adopted for the study, as outlined in the Research Methodology chapter that follows.

CHAPTER 3

RESEARCH METHODOLOGY

> *"To the extent that it is possible to do so, he or she plans thoughtfully, acts deliberately, observes the consequences of action systematically, and reflects critically on the situational constraints and action potential of the strategic action being considered."*
>
> *(Carr and Kemmis, 1986, p. 40)*

3.1 Introduction

This chapter describes the process of the research design as it was influenced by the investigation of poorly understood concepts. The first section provides a description of the action research methodology and the mixed methods approach, explaining why they were chosen for this study and providing some critiques of these approaches. It also describes the background to the study as this shaped the research design. The second section describes the sample and the resulting ethical concerns. In the third section, the investigation of poorly understood concepts in the high school physics syllabus is described, as this determined the focus area of the study. The fourth section describes the process of designing and modifying the resource intended to improve students' application of Newton's second law and the research instruments, before the process of testing them, described in the fifth section. Lastly, the methods of data analysis are described.

3.2 Research Design

This study was conducted using the action research methodology and a combination of quantitative and qualitative methods of data collection were employed, constituting a mixed methods approach. The background to the study influenced its design and the way that it unfolded and so is included under this section on research design.

3.2.1 Action Research

Action research has its roots in critical theory which aims to combine the practical objectives of 'informed practice' (*praxis*) with the "rigour and explanatory power" of scientific reasoning (Carr and Kemmis, 1986, p. 133). The strength of the interpretive view, focussing on understanding, meaning and action, is the weakness of the more positivist scientific approach, with its emphasis on explanation, prediction and control, and vice versa (Carr and Kemmis, 1986). Critical theory attempts to encourage self-reflection to identify and articulate problems such as a distortion or repression of goals so that they can be addressed (Carr and Kemmis, 1986).

The action research method was developed in the hope that, with a scientific approach, theory and practice might work alongside one another to address and understand significant social problems (Kemmis and McTaggart, 1997). While critical educational science and action research both expect self-reflection and critical scrutiny of practice, action research expects this process to lead to action. Action researchers hope to see a progression of theory as a result of their real-world interventions, rather than interventions or applications developing from theory (Carr and Kemmis, 1986).

Kurt Lewin (1946) coined the phrase 'action research' to describe the iterative process that is a "self-reflective spiral of cycles of planning, acting, observing and reflecting" (Carr and Kemmis, 1986, p. 162). The research method aims to improve practice and involve the participants, involving more and more people through the spirals in an ever-widening circle of influence (Carr and Kemmis, 1986). A National Conference on Action Research in 1981, prepared a definition of action research, which appears in a slightly adapted form in Grundy and Kemmis (1982):

> *"Educational action research is a term used to describe a family of activities in curriculum development, professional development, school improvement programs, and systems planning and policy development. These activities have in common the identification of strategies of planned action which are* implemented*, and then systematically submitted to* observation, reflection *and* change*. Participants in the action being considered are integrally involved in all of these activities."* *(Grundy and Kemmis, 1982, p322)*

This definition incorporates the spiral nature of the method described by Lewin (1952) through the idea of planning, acting, observing and reflecting. Participation is emphasised, and action research is a common choice of method when a social practice is the focus of the research (Grundy and Kemmis, 1982).

Action research offers teachers a means to overcome problems, deepen their understanding of their practice or situation, or improve their practice through the awareness brought about by linking reflection (which is often retrospective) and prospective action in the light of critical reflection (Carr and Kemmis, 1986). The role of the teacher as a participant is important as it is their experience that usually provides the problems that are under investigation (Carr and Kemmis, 1986).

> *"A critical educational science, however, has a view of educational reform that is participatory and collaborative; it envisages a form of educational research which is conducted by those involved in education themselves. It takes a view of educational research as critical analysis directed at the* transformation *of educational practices, the educational understandings and educational values of those involved in the process, and the social and institutional structures which provide frameworks for their action. In a sense, a critical educational science is not research* on *or* about *education, it is research* in *and* for *education." (Carr and Kemmis, 1986, p. 156)*

An 'outsider' rarely has the power for transformation of practices and often does not have the vested interest in the proposed change, as they will not remain after the change has been implemented (Carr and Kemmis, 1986). However, as the validity and accountability of the process of action research is debated, the 'outsider' can have an important role to play. The 'outsider' can be a 'critical friend' who assists by challenging and interrogating the researcher's self-reflection (Elliott, 1976).

The positivist view of knowledge believes that knowledge accumulates as a result of neutral and objective observations, resulting in 'truths', which remain in place until they are overthrown and replaced by a more correct or more fitting paradigm (Carr and Kemmis, 1986). The interpretive view is criticised for its inability to produce generalisations and for its lack of objective or conclusive findings, as its findings are based on observations and interpretations, which are subject to researcher's bias (Carr and Kemmis, 1986). As such, action research, as an interpretive form of research, is often criticized and brought into question as an inadequate research method where the bias of the researcher and potential self-deception compromise the authenticity and validity of the method.

Action research aims to develop knowledge systematically, which constitutes it as 'research' (Carr and Kemmis, 1986). It should be considered authentic as it illuminates findings as a result of a practitioner's careful and logical reflection on their own considered practice, albeit that there may be a gap or incongruence between their theory and practice (Carr and Kemmis, 1986). Although action research may be considered biased because the researcher is analysing or investigating their own practices, the purpose of an action research study is to improve practice (Koshy, 2010).

Karl Popper (1972) was quoted in Carr and Kemmis (1986, p. 121) as saying that "…our greatest instrument for progress is criticism." Carr and Kemmis (1986) propose that action research can be made more 'objective' if participants are willing to openly and impartially discuss and debate their views and preconceptions. They further suggest that 'theory' can acquire 'scientific' status when it offers improved ways of understanding the particular, practical experiences of teachers and that it can acquire educational validity when these suggestions are examined and proven by practical experience (Carr and Kemmis, 1986). Although the results from action research cannot be generalised, other professionals may be able to replicate the study and generate similar outcomes (Koshy, 2010).

Bell (1985) cautions that the results of action research are sometimes published in such a way as to suggest that they are more broadly applicable than they are and that sometimes an alternative method of research would have been more appropriate, but action research is seen as the default method for educational research.

Carr and Kemmis (1986, p. 189) wrote that "[w]hile practical experience can be gained through unsystematic reflection on action, a rational understanding can only be gained through systematic reflection on action by the actor involved." The intention of this study is to gain a deeper understanding of the poorly understood concepts in physics and to attempt to improve students' performance through an iterative process of intervention. The action research paradigm is well-suited to develop and test the resource for intervention.

One of the aims of this study was to develop an effective resource to enable students to improve their understanding of the application of Newton's second law. This was done through an iterative process of testing and evaluating the effectiveness of a resource in the form of a handout, refining or changing it and then testing and evaluating it again. The resource was put through four iterations to produce a product which could then be made available to students for independent use.

The success of action research is judged by the extent to which teachers develop a deeper understanding of their own challenges and practices in order to bring about change (Carr and Kemmis, 1986; Corey, 1949).

Reporting one's experiences as a self-reflexive narrative and describing it from a personal perspective is seen to enhance personal development, which is a goal of action research (Koshy, 2010). With this in mind, and in keeping with the convention of action research writing, the remainder of this study will be written in the first person, where appropriate.

3.2.2 Mixed Methods

Up until the 1990's, studies were usually conducted using either purely qualitative or purely quantitative methods. There has been, however, a growing trend towards using both methods together in one study or in one field, either in combination or sequentially. There are many, diverse definitions of mixed methods research, but Johnson, Onwuegbuzie and Turner (2007) combined the current definitions as:

> *"Mixed methods research is the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches (e.g., use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for the broad purposes of breadth and depth of understanding and corroboration." (Johnson et al., 2007, p. 123)*

Mixed methods research takes the advantages of both forms of analysis and combines them. A quantitative study may provide a baseline or eliminate outlying values in data collection, while qualitative methods can provide rich detail (Johnson, Onwuegbuzie and Turner, 2007). Quantitative data are more easily generalizable through appropriate analysis, while "qualitative data can play an important role by interpreting, clarifying, describing, and validating quantitative results" (Johnson et al., 2007, p. 115).

Employing mixed methods allows researchers to report richly on their data, while improving the quality of their research by facilitating *triangulation*. Triangulation is “the confirmation of results from one approach by those of another approach” (Flick, 2018, p. 5). Triangulation can be applied to data, theory, investigations or methods to reduce bias or broaden perspective. It aims to find an agreement in findings to improve their validity.

Mixed methods may be classified as ‘pure’ mixed (where quantitative and qualitative methods have equal status) or may tend towards more qualitative or more quantitative methods (Johnson, Onwuegbuzie and Turner, 2007). Researchers employing a quantitative dominant approach will adopt a predominantly quantitative approach, but will employ qualitative methods where these add benefit. Researchers using a qualitative dominant approach will focus on the qualitative approach, but will incorporate quantitative methods when these benefit the research (Johnson, Onwuegbuzie and Turner, 2007). The continuum is shown in Figure 3.1 below.

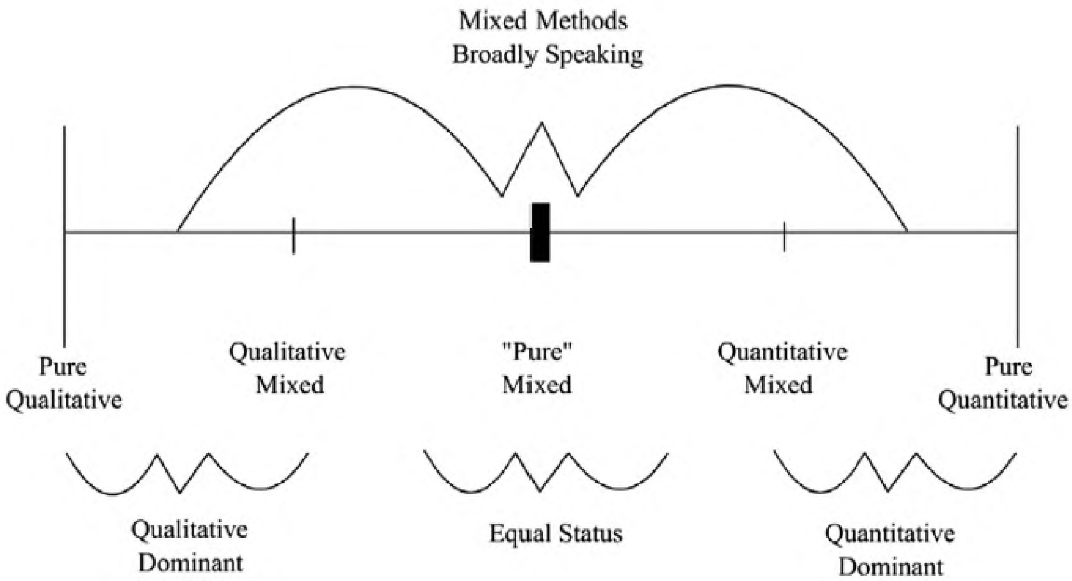


Figure 3.1: *The dominant research paradigms, including the sub-types of mixed method research (Johnson et al., 2007, p. 124).*

This study uses both qualitative and quantitative data, often drawn from the same source (see Table 3.3 on page 96). This constitutes a pure mixed method approach. Quantitative methods were largely employed in the initial determination of focus, although qualitative analysis (for example, analysing student responses in examination questions) refined and corroborated the quantitative data which is summarised graphically. The impact of the intervention was assessed using quantitative methods (pre- and post-tests), but students were given the opportunity to comment on their perception of the resource to provide richer, more in-depth feedback on the effectiveness of the resource. The transfer of learning was also evaluated by looking at examinations written after the intervention and these were assessed using both quantitative and qualitative methods.

During the evaluation of the resource, the data were collected together using a post-intervention evaluation form, but analysed separately using quantitative or qualitative methods. The students' test and examination responses were also analysed quantitatively, looking at average scores and individual improvements, as well as qualitatively when the quality of diagrams was assessed. The overall mixed method design best fits the description of a convergent parallel design (see Figure 3.2), where the data are collected concurrently, but separately, and is merged in the analysis stage to produce a rich and comprehensive discussion (DeCuir-Gunby and Schutz, 2017). The use of uppercase letters ('QUAN' and 'QUAL') indicates an emphasis on quantitative and qualitative methods respectively. A lack of emphasis on a particular method is indicated with lower case letters ('quan' and 'qual'). The convergent parallel approach suited the study context as students were only required to complete one form and the necessary information could be extracted from their tests and examinations. This design also supports triangulation, although merging the analyses can prove problematic and may reveal contradictions (DeCuir-Gunby and Schutz, 2017).

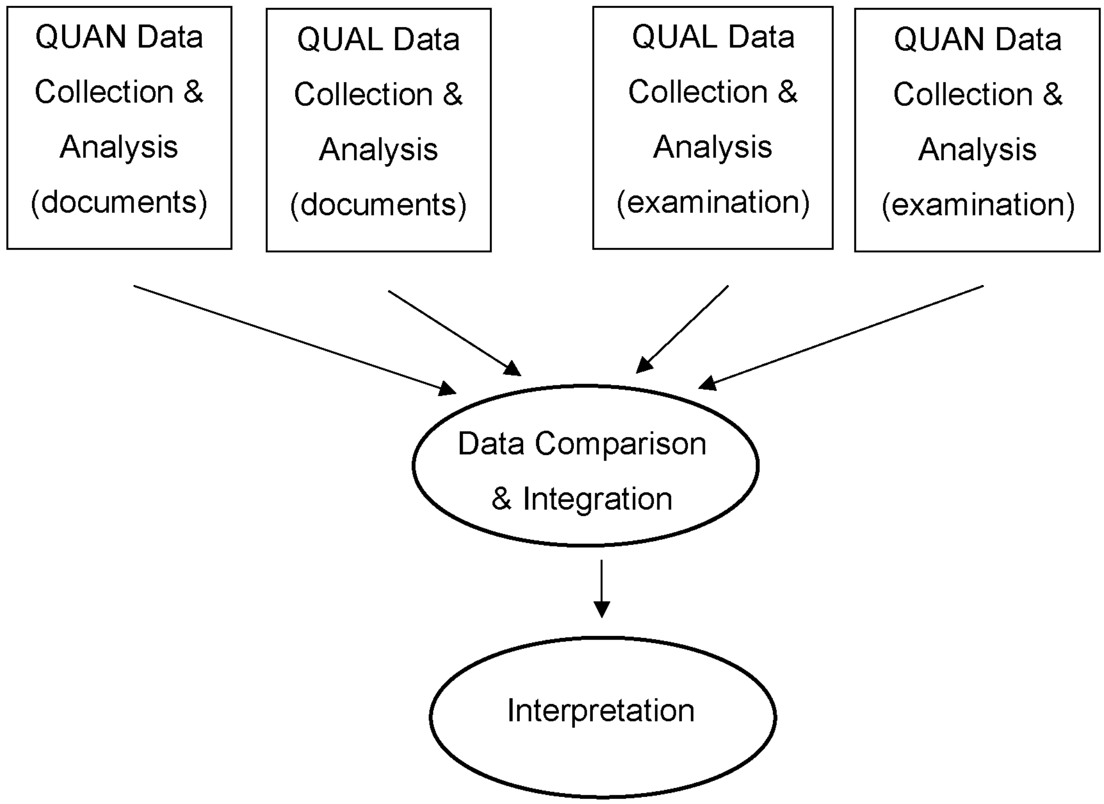


Figure 3.2: *Schematic diagram showing the convergent parallel mixed methods design for the initial identification of the focus of the study.*

This study is also multiphase, given the iterative nature of collecting and analysing data to inform the next phase where data are collected and analysed (see Figure 3.3).

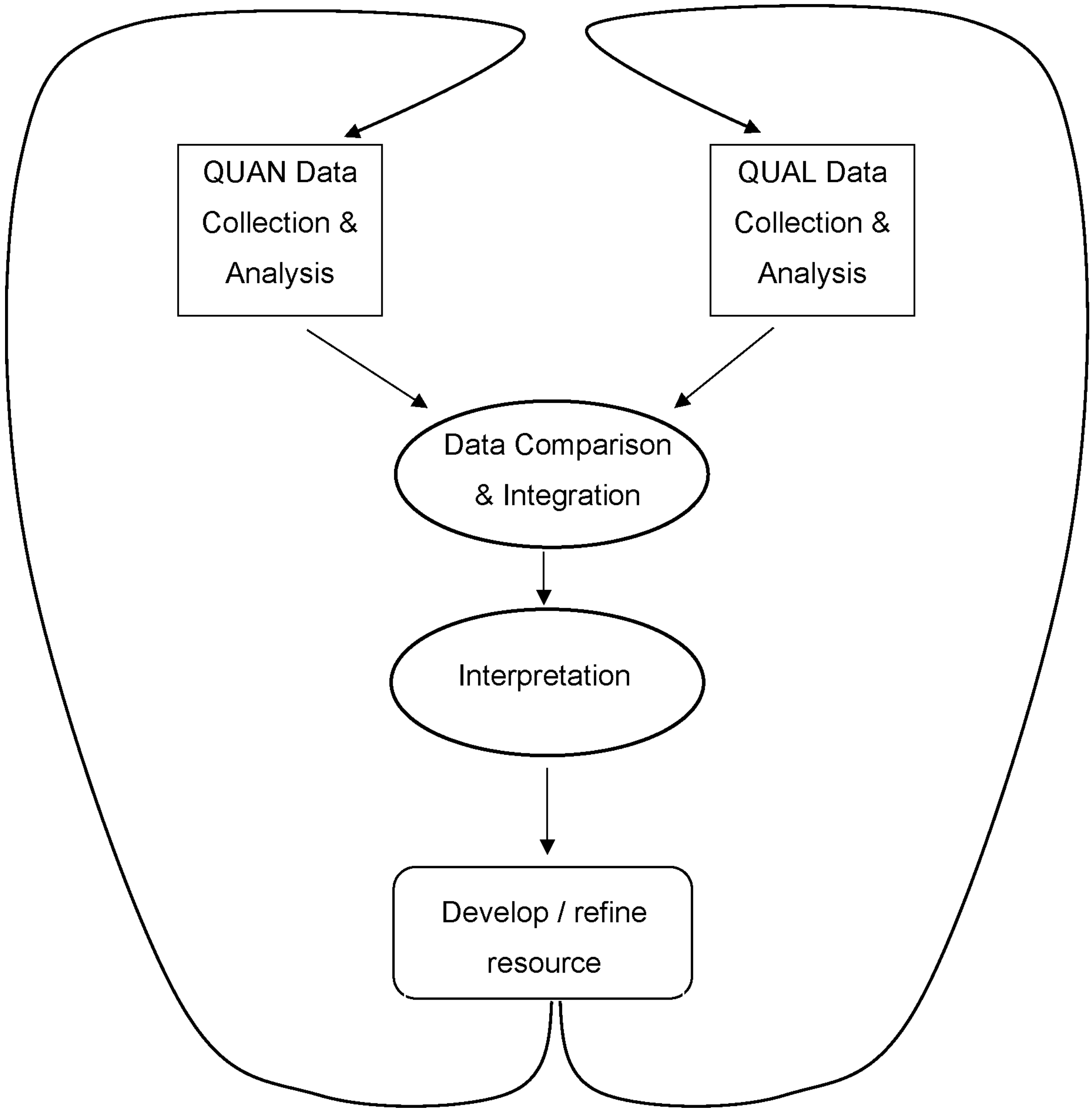


Figure 3.3: *Schematic diagram showing the iterative nature of the multiphase, convergent parallel mixed methods design for the analysis of data.*

3.3 Description of Sample and Ethical Considerations

My personal purpose for this study was to improve my practice and the resources that I make available to my students. To this end, I was mindful of the potential bias of working within my own school and made a conscious effort to be critical of my own current and adjusted practices. I wanted to test improved methods and resources objectively to achieve an optimal outcome for my students.

The sample that I chose influenced the design of my research, particularly regarding the ethical considerations and resulting procedure. It is also necessary to declare that my studies were funded by my employer, which might appear to introduce a conflict of interest. Independent schools often promote and defend our teaching methods and our resources, but a defensive viewpoint when conducting research would diminish the value of the outcome. As the schools are anonymous in this study, I was able to be critical of my practice without risk.

3.3.1 Sample Selection

As a high school physics teacher, it was convenient to use students at my school as the sample for the action-research process of developing, evaluating and improving the resource. I wished to design an intervention to help the Grade 10 – 12 students at School A and School B, as these students have chosen Physical Sciences as a subject for Grade 12. The pressure to pass Physical Sciences is considerable and low pass rates nationally (48.7 % of students scored 40% or greater in 2018), suggest that there is a need for intervention (Department of Basic Education, 2019). I am well known to the students, so I would be able to observe and interact as an 'insider' (Carr and Kemmis, 1986). Having taught at the schools for 13 years, I am familiar with the content and the methods used to teach it. I would also have access to students' test and examination responses that highlight poorly understood concepts.

My research site was the schools at which I teach in a small town in the Eastern Cape, South Africa. School A is a boys' school and School B is a girls' school, but from Grade 10 to 12 (ages 16 to 18) the boys and girls are taught together in mixed classes for most of their subjects. For ease of reference, School A and School B, will be referred to as 'The Schools' for the purposes of this study as I will treat the student cohort as a single body of students.

The Schools are relatively small (School A has 470 students and School B has 418 students). While these are expensive schools and a large proportion of the students are from economically affluent backgrounds, there is a proportion of pupils from low-income families, many of whom had attended under-resourced primary schools. The Schools are multi-racial, with students from all over South Africa, the rest of Africa and overseas. A significant proportion of students are second language English speakers. There is no entrance examination for The Schools and the range of results vary from year to year.

The Schools are 'independent' and follow the syllabus examined by the Independent Examinations Board (IEB), which differs in some topics and subtly in style from the Department of Basic Education (DBE) syllabus, although both examination bodies (IEB and DBE) set an exit examination at the end of the Grade 12 year, known as the National Senior Certificate (NSC).

Physical Sciences is one subject in South Africa: if you take Physics, you have to take Chemistry as well. The subjects each count 50% towards the final mark reported for Physical Sciences, but they are examined separately (Paper 1 is Physics and Paper 2 is Chemistry). At The Schools, Physics and Chemistry are taught by different teachers in alternate weeks. Students have nine 45-minute Physical Sciences lessons in a 2-week cycle, of which 4 lessons are Physics and 5 lessons are Chemistry or vice versa. In most grades there are approximately 24 students in each Physical Sciences class, of which there are usually 4 classes per grade. An A Level stream was introduced in Grade 11 in 2019, which resulted in 3 remaining IEB classes. Uptake of Physical Sciences at The Schools is approximately 55 %, compared to the National uptake for Physical Sciences which was 27.6 % in 2018 (calculated from number of students taking Physical Sciences, stated in the DBE Annual Report; (Department of Basic Education, 2019)). The majority of students at The Schools, particularly those who choose Physical Sciences, hope to meet the entrance requirements for university, with many striving to be accepted for degrees with stringent entry requirements such as medicine or engineering[3].

The four Physical Sciences teachers (two physics teachers and two chemistry teachers) each bring their own style to the classroom, but teaching is mostly in the traditional style, with the majority of the teaching time spent on content delivery, interspersed with problem-solving. In physics, demonstrations are used and practical work is done in some sections, but not as regularly as in chemistry. Students have the opportunity to attend 'Support' in the late afternoon each week, which is an opportunity for them to bring specific questions or problems for individual or small group assistance from teachers, or to catch up concepts that they may have missed or not fully understood.

Teachers at The Schools have produced notes for physics and for chemistry, which are used in class. These include explanations, examples and practice worksheets. Topics are taught in modules, rather than the more common approach in South Africa, which is to revisit topics each year, adding greater detail or depth each time (known as 'spiralling'). Concepts are cumulative and examinations are written in July / August and November each year, with the exit examinations in November of the Grade 12 year. The July / August and November examinations are internal assessments, which are set, moderated and marked by teachers at the schools.

[3] Physical Sciences is a prerequisite for both medicine and engineering courses.

I chose to involve all the Grade 11 and Grade 12 Physical Sciences students in 2018 and 2019 at The Schools as a convenience sample to assess understanding and test the effectiveness of the intervention, during the development process. These students were taught either by the other physics teacher or by me. My colleague and I taught the physics concepts as we have always done, as this intervention was intended to complement or provide additional learning opportunities.

3.3.2 Ethics Clearance and Introduction of Study to classes

In order to use the students' responses to test and examination questions and to test the effectiveness of my intervention with pre- and post-tests and evaluation forms, I was granted ethical clearance by the Rhodes University Ethics Standards Committee (RUESC) (see Appendix A.1 and Appendix A.2). I requested permission from the Heads of The Schools to conduct the study in their schools and to approach students and their parents for their consent (see Appendix A.3). I emailed the parents of the 270 Physical Sciences students to request permission for their son's or daughter's participation in my study (Appendix A.4) and received a 66,3% positive response return.

I teach half of the physics students and was able to tell them in class time about my proposed research and invite them to participate in the process. I visited the other classes to invite them to participate. Conscious that my position of authority as a teacher may pressurise students to participate, I emphasised that the purpose of this study was to improve my practice and to develop a better resource for their learning. By addressing my request for participation to the whole class, I believe that I placed minimal pressure on individual students to participate, should they not wish to. All 270 students were given consent forms (Appendix A.5). I emphasised that participation in the research was entirely voluntary and that the students were under no obligation to give their consent to participate. They could hand back their forms declining to participate and they could withdraw from the study at any point. I received the most responses from students and parents in the Grade 12 group, while the Grade 10 group returned the fewest responses.

All students had to write their tests and examinations as usual, but I would only use the responses of those who had given their consent for my research. All students would have the opportunity to use the revision resources, but I would only analyse the responses of those who had given their consent to participate in the study. The examination and test responses were coded to ensure anonymity.

Although 95,8% of students signed assent, many parents did not return their consent forms, leaving me with a sample of 189 students for whom I had individual and parental consent. Nineteen of these students indicated a willingness for me to use their responses in assessments, but did not give their consent for me to use their responses to the revision resources.

Table 3.1: *A summary of the number of participants from The Schools.*

Iteration	Date	Grade	Number of girls	Number of boys	Total number of participants[4]
1	September 2018	12	32	49	81
2	October 2018	11	19	29	48
3	July 2019	12	19	29	48
4	July 2019	11	20	21	41

[4] This was the number of participants who gave consent and whose parents gave consent for me to use their responses in examinations

3.4 The Research Process

The aim of this research was to identify the concepts in the South African physics curriculum with which students struggle most often and to design an intervention to assist students in improving their conceptual understanding of physics. This section describes the process of identifying the topic for the intervention, through quantitative and qualitative document analysis of past results nationally and at The Schools. It then describes the process of designing the intervention resource and the tools that would be used to test its effectiveness. This is followed by a description of the four iterative interventions that tested the resources, giving a description of each one as they were all in slightly different contexts, using an adjusted resource. The effectiveness of the intervention was assessed using pre- and post-tests and its perceived value was assessed using an evaluation form. I used the results from each evaluation to improve the resource for the next intervention in an action research cycle (see Figure 3.4). Lastly, the methods of analysis of the results are then described.

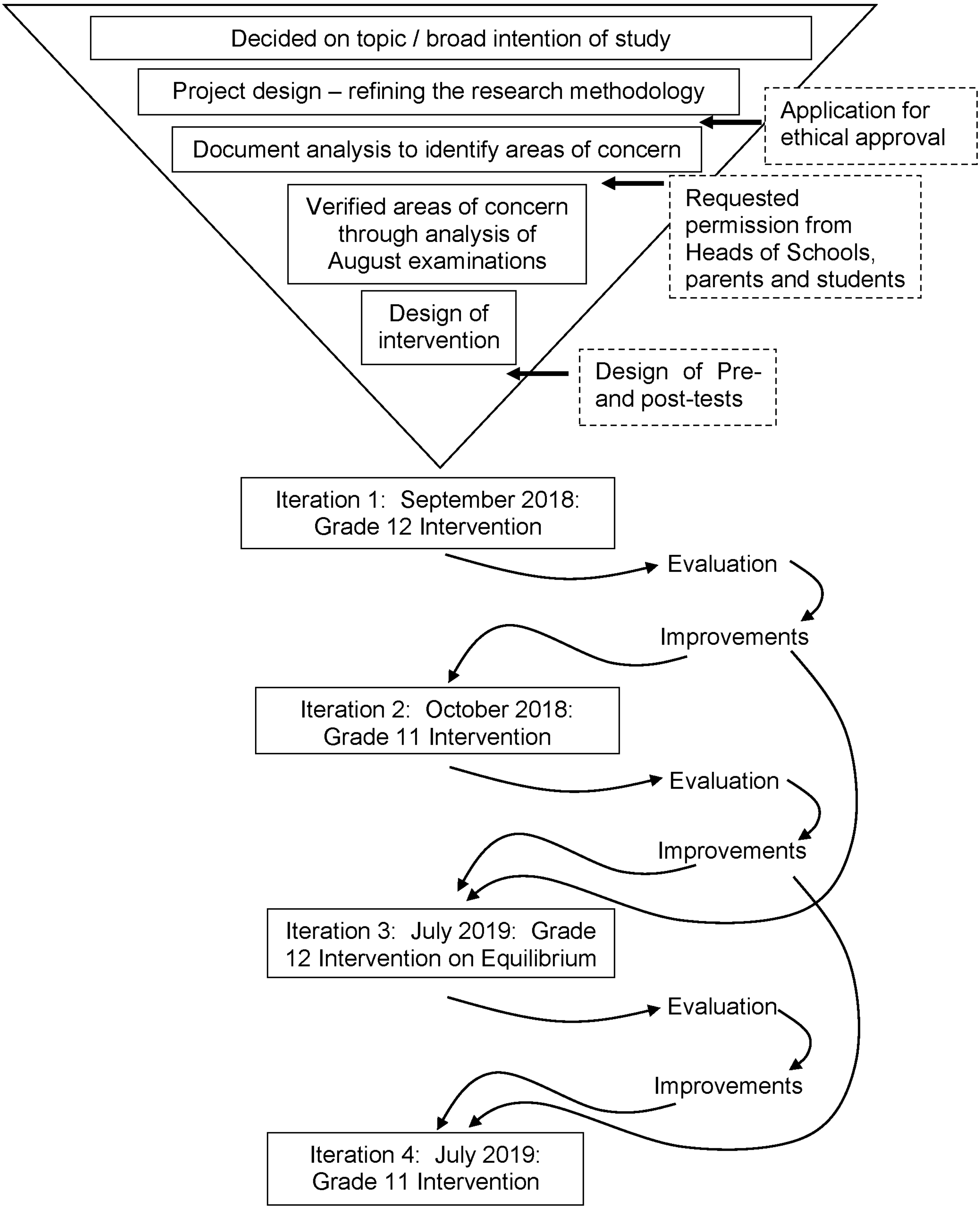


Figure 3.4: *Timeline showing the iterative process of the research design.*

3.4.1 *Choice of Topic for Intervention*

From experience, I had an idea as to which were the most problematic concepts, and I also considered focussing on those that would be difficult to self-teach from our notes or from a textbook. However, I wanted a more objective means to select problematic topics to target. Examples from literature provided a global perspective of problematic topics, while document analysis of the South African examinations gave a national perspective, and quantitative analysis of my own students' results identified their conceptual pitfalls.

Each year the National Senior Certificate (NSC), the South African Grade 12 exit examination, is administered by two bodies: the National Department of Basic Education (DBE) and the Independent Examination Board (IEB). The performance of students in these examinations is recorded and analysed by the respective bodies and each examination body publishes a report detailing the performance of student groups in each subject. The DBE publishes Annual Reports (Department of Basic Education, 2019) containing feedback on student performance in the NSC examination, highlighting problem areas and concepts, and suggesting required action by teachers to improve performance or understanding. The IEB publishes an Examiner's Report for each paper, which contains generalised feedback and common errors identified in the marking process (Independent Examinations Board, 2019). The IEB also provides each school with an Itemised Data Capture (IDC) report, which gives the average score per question for their students, compared to the average score by all students who wrote the IEB paper.

I analysed the 2014 – 2017 DBE and IEB reports to identify the broad topics in the physics curriculum which are not well understood by Grade 12 students and, more specifically, by the students that I teach. I noted the years in which each topic was mentioned in the reports and the years in which the average score for questions on a topic was below 50%. In the case of the IDC results for The Schools, I looked at questions in which the average scores were less than 5% above the IEB average. The reason for this is that The Schools usually scored higher than the IEB average. My findings are included in Chapter 4 (Figure 4.2 and Figure 4.3).

Over the years, my colleagues and I have analysed the responses and produced a summary of the average score per question for each physics examination written by the Grade 10 to Grade 12 students at The Schools. These results have informed our teaching.

I used the average score for each topic in examinations at The Schools, from 2012 to 2017, to identify areas of the curriculum that are low-scoring (Figure 4.4). This information gives a very broad sketch of the historical profile of examinations. Some questions are set at a more challenging level than others and the cognitive level of the questions on each topic varies each year. The value in looking at a longer timeframe, was to establish whether the same topics and concepts were always problematic or whether it was just the influence of the current examination style or some other transient factor.

As a pilot project, I prepared videos teaching and clarifying concepts on electric circuits for the Grade 12 group and set up an evaluation form (Appendix B), which the Grade 12 students could complete once they had used the resources. This allowed me to trial a method of delivery and some evaluation questions. Many students only watched a small part of the videos (reported by YouTube) and I decided against using videos as my method of intervention.

After analysis of documents, along with support from relevant literature, my choice for the intervention was the application of Newton's second law on an incline for the intervention. This also happens to be a section in which the NSC and IEB content and expectations are very similar, unlike some other sections of the Physical Sciences curriculum.

This was corroborated when I studied the answers to question 3.1 in the Grade 12 August 2018 examinations (see Appendix C) and Questions 5, 6 and 7 of the Grade 11 August 2018 examinations (Appendix D). Examples of student answers are given in Chapter 4.

I hoped to improve students' problem-solving strategy alongside their understanding of Newton's second law and its applications. I intended doing this by modelling the use of diagrams, as recommended by the literature (Section 2.5.7).

3.4.2 Resource Design Considerations

My review of literature, as well as my experience with the pilot project (addressing the Grade 12 group's difficulties with electric circuits), influenced my decision to use a hard-copy handout for the purpose of revising the concept of Newton's second law and its application.

This section provides a brief discussion of why some approaches were not adopted, to address the more obvious questions raised by those familiar with this field and current developments therein.

I initially believed that a *teaching* resource (a resource that *taught* a concept) would be most effective. However, through my reading, I was convinced that focussing on the students' *learning*, rather than my teaching would have greater impact. Redish (1994) sums this up very well with his extreme interpretation of constructivism:

> "You cannot teach anyone anything. All you can do as a teacher is to make it easier for your students to learn." *(Redish, 1994, p. 798)*

Reif (1978) suggested that with the increase in available technology, some material could be made available to students to work through. However, this is usually content delivery. I wanted to focus on creating a resource that would encourage students to recognise and engage with their misconceptions to assist in leading to conceptual change (Section 2.2.4) (Sutherland, 1992; Posner et al., 1982).

The learning gains reported when peer interaction has been adopted made it a very attractive approach for intervention. However, it was not adopted in this study as the problem-solving style of assessment that we are currently constrained to using does not match the more conceptual approach favoured by peer interaction. If you want to value conceptual understanding, you have to examine it (Hewitt, 1983; Mazur, 1995).

When devising my method, I considered using the Force Concept Inventory (FCI) developed to assess understanding (see Section 1.4), but it was difficult to tailor to my specific needs. I wished to target only the application of Newton's second law, with specific reference to inclines, while the FCI covers all three of Newton's laws. I could have selected questions, but, given the timing of the intervention (just before examinations, in three of the iterations), I wanted to be able to give the answers and feedback on the questions so that the students could learn from the experience and, hopefully, adjust their misconceptions. In all instances the feedback on the post-test was given online and providing answers and explanation of the FCI questions would be a breach of the etiquette of using the FCI, which stipulates that the answers are not shared. I was able to provide remedial feedback through the intervention (see Appendix F.5). The process of self-diagnosis is an important learning tool, as students can learn from their mistakes and their engagement with problems or concepts that they have to grapple with to assimilate (Cohen et al., 2008).

In my original research design, I had intended to interview students broadly about their understanding of physics and how they study physics and, particularly, to discover how successful students build an understanding of concepts. As the project developed, these interviews did not take place, as my ethics approval was granted just before the students began writing their mid-year examinations, when it would have been unethical to ask them to spend time on something that was not examination preparation. I ran the first test of the resource that I developed at the next opportunity and so my interview questions regarding the effectiveness of the resource were more relevant. I had three students volunteer for an interview and I did not have consent from the parents of one of the students who volunteered, so could not use his responses. I conducted semi-structured interviews, using some guiding questions and then following up the student's responses with clarifying or further questions. Conducting think-aloud analyses of students' answers to test and examination questions would have provided valuable insight, but was not possible due to the timing of the test just before examinations and the examinations at the end of the term.

3.4.3 *Development of the Resource*

The aim was to design a resource that could be used by students without the need of assistance from a tutor or teacher. This would require sufficient prior knowledge, guidance and instruction, as well as bridging from one task or concept to the next for students to be able to work through it by themselves. I produced a resource (Appendix E.1), guided by the design principles drawn from my review of literature, as summarised in Section 2.6. This resource was a document with some revision notes, followed by a series of structured, scaffolded worked examples, with annotations to coach the student to a deeper understanding. There were some routine examples without real-world context, progressing to more complex examples. The resource contained a number of examples to promote categorisation (Section 2.5.12) and schema acquisition (Section 2.1.6). Modelling of structured problem-solving approaches was evident in all worked examples and solutions, with an emphasis on the drawing of free-body diagrams (for each problem), which has been shown to improve understanding and application (Mason and Singh, 2016b). The resource was followed by a revision worksheet with varied, real-world questions using mixed and sometimes multi-step approaches ('exploring' as described by the theory of cognitive apprenticeship), such as students should expect to see in their examinations. The solutions to the resource and to the revision worksheet were provided to encourage self-diagnosis (Section 2.5.10) and self-explanation (Section 2.5.9).

More specifically, the resource (see Appendix E.1) [with reasons or reference to relevant theory] included

- the prior knowledge as a checklist of content knowledge that they were expected to have and that they would apply in the resource [assisting in constructing a knowledge structure (Section 2.5.12.5.1)]
- a section revising key points critical to applying Newton's second law correctly [to reduce cognitive load as content is accessible in the resource]
- four examples requiring vector addition in one and two dimensions [an example of 'coaching' - (Collins, Brown and Newman, 1987)]
- four different vectors to resolve into components [another example of 'coaching' (Collins, Brown and Newman, 1987)]
- a vector sum of two vectors that were not at right angles to one another [an example of 'exploring' according to the cognitive apprenticeship model, as this is applying concepts that have been modelled and practiced in a more complex example; (Collins, Brown and Newman, 1987)]
- eight different examples involving an object (or system of objects) on an incline, requiring a determination of force or acceleration [repetition to acquire schemas (Sweller, 1988)]
- two routine examples where a force is applied to an object at an angle to the surface that the object was resting on and students are asked to determine the frictional force between the surface and the object [an example of 'scaffolding' (Collins, Brown and Newman, 1987)]

- an algebraic example where a force is applied at an angle that required the solution of simultaneous equations to solve [increased cognitive load, once schemas are acquired (van Gog, Paas and Sweller, 2010)]
- a short explanation of an equilibrant force, which is a term that we do not use in our notes, but the concept helps with some of the examples which students encounter in this section
- a short reminder about an object in equilibrium
- three different examples involving objects in static equilibrium [an example of 'coaching' - (Collins, Brown and Newman, 1987)]
- a reminder about the work-energy theorem as this is often assessed alongside Newton's second law and work-energy theorem examples are often on inclines.

The resource was designed to emphasise fundamental concepts, showing how almost all problems in the section on Newton's second law application can be solved using the mathematical techniques of resolving forces into their components and finding a vector sum. By scaffolding the examples, students were able to do an example that, at first glance, they would have thought was beyond their ability to solve. The scaffolding was used to make complex examples more accessible and to guide students to understanding.

The bulk of the resource was a series of examples, encompassing the most common scenarios in which an understanding of Newton's second law is tested, which were very similar and repetitive, but each example required a slightly different approach. This repetition of similar processes was intended to assist with schema acquisition, by reducing cognitive load as the processes became more familiar (Paas, Renkl and Sweller, 2004). This was intended to elicit an understanding through a repetition of process using slightly different contexts and to guide students to recognise the similarities in problems, which is described as 'categorisation' in the literature (Section 2.5.12). There was a significant emphasis on objects on inclines because this had emerged as a problem.

At the end of the resource there was a scaffolded set of exercises to test retention of concepts and to give students the opportunity to solve problems in a normal test or examination-type question (see Appendix E.2). The examples in the worksheet reiterated the examples in the resource, but with real-world context, so increasing cognitive load, once schema were acquired (Sweller, 1988). This would be considered 'exploring' in the theory of cognitive apprenticeship (Collins, Brown and Newman, 1987).

Schell and Butler (2018, p. 6) describe feedback as "one of the most powerful drivers of learning because it enables students to check their understanding and address any potential gaps." The answers to the worksheets at the end of the resource were made available to students to allow them to check their answers through a process of self-diagnosis.

The effectiveness of this resource was tested with four iterations, as described resource and its administration for each iteration. As each iteration was slightly different, and the changes made were influenced by the feedback from the evaluation of the resource, I will describe the differences between the versions of the resource below in Section 3.4.5.

Each iteration was comprised of:

- A pre-test
- Administration of the resource
- A post-test
- An evaluation of the resource
- A test of transfer (usually a question in the subsequent examination)

Each of these parts of the iterations is described in the sections that follow.

3.4.4 Development of the Evaluation Instruments

To evaluate the effectiveness of each intervention, I designed a pre-test (Appendix F.1 and Appendix F.2) to gauge initial understanding of the concepts and then a post-test and evaluation form (Appendix F.3 and Appendix F.4) to be completed after students had engaged with the resource. The pre- and post-tests consisted of five multiple choice questions, which I expected students to answer in no more than 10 minutes:

- Question 1 tested their understanding of object in equilibrium.
- Question 2 tested their understanding of the effect of applying a force at an angle on the magnitude of the normal force acting on an object on horizontal surface.
- Question 3 was a conceptual question about the components of the weight of an object on an incline.
- Question 4 required students to distinguish between the maximum static frictional force and actual frictional force (force required to maintain equilibrium) acting on an object on an incline.
- Question 5 tested the student's ability to set up an expression using the forces (and components of forces) acting on an object on an incline using Newton's second law.

The post-test was identical to the pre-test, although in some iterations I changed the order of the distractors. The pre- and post-test questions were designed to test students' understanding of the core concepts and so were uncomplicated by context or additional detail.

I chose to use multiple choice questions (MCQ) to gauge the effectiveness of the intervention. I also felt that MCQs would reduce the language problems that English second-language speakers might experience. Choosing a carefully-worded option, rather than having to write an answer, may reduce any barriers to expression, such as having to remember the vocabulary particular to the concept, and better tests a student's conceptual understanding.

Li and Singh (2017) mention that a major drawback of a pre- and post-test method of assessing understanding, is that the student's thought processes are not explicit. However, multiple choice questions are a useful objective method to determine trends and can be combined with more qualitative data collection which provides insight into the rationale behind the students' answers and can reveal or confirm misconceptions (Li and Singh, 2016).

Students completed and returned hard copies of the pre-test before I handed out the resource. The results are given and discussed in Chapter 4. Google Forms provided a convenient platform to administer the post-intervention tests, as students were able to access the tests individually from their own devices in their own time and at the end of the intervention, I was able to provide feedback (see Appendix F.5). All students at The Schools have access to technology, enabling the use of Google Forms, and their answers were captured in a spreadsheet directly through the use of the form. However, with the Grade 11 group in October 2018 (Iteration 2), it was most convenient to hand out and then collect hard copy post-test forms because of the way the resource was used and because I had had such a poor return of electronic forms from the Grade 12 group a month previously.

I did not use an evaluation form for the first iteration, as I intended to interview students. However, for the remaining interventions, I used an evaluation form to capture responses from as many students as possible. The questions offered checkbox options, Likert scale or multiple-choice questions, which would all be quick to answer, with a few questions asking for more detailed responses (Appendix F.4). I used similar questions to establish the extent of the student's preparation to those used in the pilot study with the Grade 12 group.

I had piloted an evaluation form with the Grade 11 group prior to their test on the application on Newton's second law. This was adapted for the form that I distributed after Iteration 2.

The evaluation form for Iteration 2 (see Appendix F.4) asked the students to:

- Give their name (optional)
- Indicate whether or not they had worked through the revision resource on forces (described in Section 3.4.2) and the appropriate option to indicate the extent to which they had worked through it.
- select the option that describes the effect of the resource on their understanding of the section.
- explain why the resource improved their understanding (open-response)
- explain why the resource confused them (open-response)
- select options to indicate whether they would have spent time on the resource out of class and
- select options to indicate how long they would spend on this kind of activity on their own.
- suggest any improvements that could be made to the resource (open-response).

The free-response questions on the evaluation form provided an opportunity to collect rich feedback from students in a non-personal, non-threatening forum.

The evaluation form was also adjusted with each iteration of the intervention and the changes made are described in Section 3.4.5.

3.4.5 *Testing the Revision Resource*

Versions of this resource were given out to groups of students four times, each time testing its effectiveness in improving their understanding of Newton's second law and its application, and using the feedback provided by students to improve the resource.

Table 3.2: *A summary of the interventions using the resource.*

Iteration	Date	Group	Number of participants[5]
1	September 2018	Grade 12	82
2	October 2018	Grade 11	48
3	July 2019	Grade 12	48
4	July 2019	Grade 11	41

3.4.5.1 Iteration 1: Grade 12 Revision Camp, September 2018

In September each year, The Schools organise a Revision Camp, which is open to all Grade 12 students at The Schools and is intended to kick-start their revision for their final examinations. In a one-hour session with two groups of Grade 12 students during this camp, I revised Newton's second law and its applications. The session began with a (hard copy) pre-test and then I taught for 45 minutes, revising the concepts that were outlined and working through selected examples on the board for the students ('modelling' according to the cognitive apprenticeship model). Students were expected to work through the resource and then complete the post-test online (using Google Forms) and answer some questions evaluating their perception of the value of the resource. Few students completed the post-test.

[5] This was the number of participants who gave consent and whose parents gave consent for me to use their responses in examinations

The pre- and post-tests were identical, with the post-test available online. Many students reported verbally that they were confused by this and thought that there was duplication, as they had already completed the test. They cited this as their reason for not completing the post-test.

To assess the transfer of conceptual understanding, I looked at the results for The Schools in the IDC reports provided by the IEB for the NSC November 2018 examination (Appendix G).

3.4.5.2 Iteration 2: Grade 11 Revision, October 2018

I modified the resource to include more explanation in the hope that this would make it easier for students to use it independently. I included more worked examples ('modelling') to guide students in how to approach questions, rather than me demonstrating the method on the board as I had done with the Grade 12 group. The explanation included prior knowledge at the start of the resource, and the worked examples included free-body diagrams and equations to model multiple representations of a problem (Greeno, 1989). The rest of the resource was largely unchanged, although I removed the explanation of the equilibrant force and the section on objects in static equilibrium to shorten the resource. I shuffled the examples in the worksheet at the end of the resource and removed the examples that involved energy considerations and the examples that were beyond the scope that we expect of a Grade 11 student. These were replaced with more relevant examples.

The second time this intervention was used was when the Grade 11 group was preparing for examinations (Figure 3.4). We had just taught the work-energy theorem and revised Newton's second law in the questions in this section. Based on my experience with the Grade 12 group, we used class time for this intervention so that, although the students were working through the resource individually, there was time allocated for the task and my colleague and I could encourage them to stay on task and complete the resource in class. My colleague followed the same approach with his classes.

The students answered the pre-test questions on paper and handed their responses in before being given the resource to work through in class, asking questions when they needed to. For the most part, the students were able to work through the examples on their own, but many of them asked questions and both my colleague and I did a few examples on the board. The majority of students used three 45-minute lessons to work through the resource and some spent time on it outside of lessons in order to finish by the end of the third lesson. A full worked memorandum was made available online during the third lesson for students to check their answers. Students were encouraged to ask questions in this lesson or at the Support opportunities in the afternoons.

The students completed the post-test (hard copies were distributed at the end of the third lesson) and an evaluation form was made available online after the intervention, but only eight students responded. Due to the timing of the intervention (just before examinations), I did not have the opportunity to interview any students about their reaction to the intervention, but verbal responses in class were positive and a number of students requested that I produce similar resources for other topics. To evaluate the impact of the resource and the successful transfer of understanding, I studied the performance of the consent sample in the questions on the application of Newton's second law in the Grade 11 November examinations (Questions 1.3, 1.4, 1.5, 4 and 5, Appendix H) and the way that these questions were answered.

3.4.5.3 Iteration 3: Grade 12 Examination Revision, July 2019

The results from the Grade 11 evaluation revealed a problem with the concept of forces in equilibrium. The answers to the first question on the pre-test were not significantly improved in the post-test. On evaluation of the resource, I noticed that there was, in fact, very little said about an object in equilibrium, with just two references to it in the revision text. In the run-up to mid-year examinations, I administered the pre-test (hard copy) to all the Grade 12 classes (the previous year's Grade 11's) to see whether the misconception persisted. I then gave out a new resource (included in Appendix E.3) focusing on objects in equilibrium, with expanded notes and worked examples focusing on objects in equilibrium, as well as some exercises to check their understanding on completion of the resource. The Grade 12 students were encouraged to complete this and then to check their answers online (Appendix E.3 and Appendix E.4 were provided online) and complete a post-test and an evaluation form online. I reminded them on two occasions about the online resources and gave them an opportunity to complete the form in class when they received their examinations back, if they had not already done so. After a poor response to this request, a new form was issued, just asking students to indicate whether they had completed the resource fully, partially or not at all, which 76 % of participants returned.

One of the multiple-choice questions (Question 1.5 in Figure 4.26) and one of the long questions (Question 3 in their mid-year examination, provided in Appendix I) were intended to test their understanding of the application of Newton's second law. Student responses are shown in Chapter 4 (Section 4.4.3).

3.4.5.4 Iteration 4: Grade 11 Examination Revision, July 2019

The first version of the resource included the work-energy theorem as this is a common application of Newton's second law. I removed this section from this last version of the resource because we only teach it in September and so the Grade 11 group had not yet covered the concept. I merged the additional notes that I had included for the Grade 12 group on objects in equilibrium into the previously revised resource and included more worked examples with explanations of steps (See Appendix E.3).

The Grade 11 group had just completed the section on forces acting at an angle and objects on an incline. They wrote a test on this section (Appendix J), which I evaluated as a baseline. In the last two lessons before examinations, I handed out the pre-test and then gave them an opportunity to work on the revision resource in class, in the additional revision opportunities in the afternoons, or in their own time. They asked a few questions, but mostly worked through the resource independently. Full worked solutions to the entire resource were posted online, as well as solutions to the revision worksheet at the end of the resource. Students were encouraged to ask questions in class or at the Support opportunities. Students were asked to complete the post-test and an evaluation form online once they had completed the resource and checked their answers against the solutions posted online. After a poor response to this request, a new form was issued, just asking students to indicate whether they had completed the resource fully, partially or not at all. 79 % of the Grade 11 participants returned this form.

The Grade 11 August examination (Appendix K) was set to test transfer of learning from the test and the resource. The multiple choice question 1.4 tested the same concept as question 1.1 in the test, but with algebraic answers, rather than a numeric calculation. Question 3 was similar to the exercises at the end of the resource and question 4 was similar to question 3 in the test. I studied student responses in the examination.

3.4.6 *Methods of Data Analysis*

Table 3.3: *A summary of the data analysed and the broad methods used.*

Data	Source	Nature	Method of analysis[6]
National itemised data capture (2014 – 2017)	IEB	Graphs	QUAN
Examiner's reports (2014 – 2017)	IEB	Document	QUAN
Examiner's reports (2014 – 2017) including question summary	Department of Basic Education	Document with graphs	QUAN
Itemised data capture for School A and School B (2014 – 2017)	IEB	Graphs	QUAN
Examination response summaries (2012 – 2017)	The Schools	Graphs	QUAN
August 2018 Grade 11 Examination	The Schools	Document	QUAN + QUAL
August 2018 Grade 12 Examination	The Schools	Document	QUAN + QUAL
Intervention 1	The Schools	Student responses	QUAN + qual
Interview	Selected students	Verbal	QUAL
Intervention 2	The Schools	Student responses	QUAN + QUAL
Itemised data capture for School A and School B (2018)	IEB	Graphs	QUAL
Intervention 3	The Schools	Student responses	QUAN + QUAL
Intervention 4	The Schools	Student responses	QUAN + QUAL
July 2019 Grade 11 Test	The Schools	Document	QUAN + QUAL
August 2018 Grade 12 Examination	The Schools	Document	QUAN + QUAL
August 2019 Grade 12 Examination	The Schools	Document	QUAN + QUAL

[6] quan and qual represent quantitative and qualitative methods, respectively. Upper case letters (QUAN and QUAL) indicate an emphasis and '+' indicates that the methods are used or data are collected concurrently or simultaneously (DeCuir-Gunby and Schutz, 2017).

The MCQ answers given by all students in each pre-test and post-test were summarised in bar graphs. A comparison was also made of the pre- and post-test scores for individual students. These results are summarised in Table 4.1.

The average normalised gain was calculated for each iteration to evaluate the success of the intervention. Pre- and post-test scores were only included for students who completed both tests. This is called '*matched data*' and is preferred as it prevents an inflation of gain by using scores of students who did not complete both tests (Hake, 1998; McKagan, Sayre and Madsen, 2016; Nissen et al., 2018). The average normalised gain is calculated by

$$< g > = \frac{<\%\mathrm{post}> - <\%\mathrm{pre}>}{100 - <\%\mathrm{pre}>}$$

Where <*g*> is the average normalised gain,
<%post> is the average post-test score,
<%pre> is the average pre-test score.

The average normalised gain indicates what was learnt through intervention (Meltzer, 2002). This calculates the improvement as a fraction of the maximum possible improvement, which allows for the range of pre-test scores (Bates and Galloway, 2012). Hake (1998) defined the average normalised gain as being high (<*g*> >0.7), medium (0.7 > <*g*> >0.3), or low (<*g*> <0.3). Gains of 0.3 and above (where students improve their score by at least one third of the maximum possible improvement) are considered to indicate successful interventions (Bates and Galloway, 2012). The average normalised gain values for each of the four iterations can be found in Table 4.1.

A statistical *t*-test was performed to evaluate the significance difference between the pre- and post-test scores for each Iteration. I also tested for a significant difference in the gain in pre- to post-test scores between those who reported to have used the resource and those who reported that they did not use it in Iteration 3 (Grade 12 2019). In the same Iteration, I also tested for a significant difference between the scores for Question 3 in the Grade 12 August

2019 examination for those who had used (or partially used) the resource, compared to those who did not use it. In addition, I tested for a significant difference in the gains from pre- to post test for those who had used (or partially used) the resource, compared to those who did not use it in Iteration 4 (Grade 11 2019). All the *t*-tests were one-tailed. Significant differences between the sets of data were inferred when the *p* value was less than 0.05 (meaning a 95% or greater chance that the difference can be attributed to the use of the resource).

In addition to looking at individual improvements in scores on the pre- to post-test and looking at the average normalised gain, I wanted to assess whether the intervention had affected the diagram-drawing habits of the students, as improved diagram-drawing can improve problem-solving. Studying the number of diagrams is easily quantified objectively (Mason and Singh, 2016b). In the examinations written in November, a tally was made of the number of additional diagrams or free-body diagrams that were drawn by students (over and above the diagrams that they were instructed to draw). In these tests we looked at the entire consent sample as a whole.

In the August 2019 examinations, using the responses by students of whether they had worked through the resource fully, partially or not at all, the students were separated into each of these three groups. A comparison could then be made of their average normalised gains from pre- to post-test, the number of diagrams that they drew in addition to those they were instructed to draw and, in the case of the Grade 11 group, their scores on the relevant questions in the test (written just before the intervention) and the examination (written shortly after the intervention).

The quality of diagrams drawn has been shown to be relevant in predicting problem-solving success (see Section 2.5.7.1). I developed a rubric (Table 3.4), which was used to assess the quality of the free-body diagrams drawn in the 2019 Grade 11 and Grade 12 August examinations, by all students in the consent sample. The average scores according to the rubric were again compared across the three groups (completed resource, partially completed resource and did not complete resource).

Table 3.4: *Rubric to assess the quality of free-body diagrams drawn in the August 2019 examinations at The Schools.*

	Orientation of diagram	Concept of F_N	Components	Identifying forces	
In equilibrium (G11 Aug 2019 Q3)	Correct orientation	$F_N < F_g$		All forces shown correctly	No additional forces shown
On an incline (G11 Aug 2019 Q4)	Correct orientation	F_N perpendicular to incline	Components shown (correctly)	All forces shown correctly	No additional forces shown
Accelerating block (G12 Aug 2019 Q3)	F_N perpendicular to surface	$F_N < F_g$		All forces shown correctly	No additional forces shown

CHAPTER 4

RESULTS AND DISCUSSION OF RESULTS

"So action research is about working towards practical outcomes, and also about creating new forms of understanding, since action without reflection and understanding is blind, just as theory without action is meaningless." *(Reason and Bradbury, 2001, p. 2)*

The results of this study are presented and discussed in this chapter, with reference to the literature reviewed in Chapter 2 and the method described in Chapter 3.

The aims of this study were described by the research questions (Section 1.3), which guided the approach. They were:

- to determine which are the physics topics that are most problematic in the South African Physical Sciences curriculum and
- to determine whether students' performance can be improved through the use of a targeted intervention in one of these problematic topics: the application of Newton's second law.

The first section below discusses, through the perspective of the learning theories described in the literature review (Section 2.2), how the possible solutions that have been tried by others (Section 2.5) may assist in reducing the difficulties that students experience in their understanding and application of physics. The design of the resource and evaluation tools are then discussed with some justification as to the choice of methods and approaches. This section also provides the analysis of documents that addressed the first aim of this study and determined the choice of Newton's second law and its applications as the topic for the intervention.

The next section presents the findings to address the second aim of the study and provides discussion on these findings. The first part summarises the results for all four iterations of the interventions, describing and discussing the results of the pre- and post-tests of conceptual understanding of Newton's second law and the calculated average normalised gain as a measure of the success of the intervention. The second part looks at each intervention separately (organised chronologically) and gives the results of the various measures used to test the effectiveness of the intervention, including the responses given by students in their evaluation of the intervention, as well as some discussion of the results. These measures are described in detail in Chapter 3. I have included some discussion of the justification for improvements, where appropriate, since the intention was to improve the resource, the method and the evaluation process of each intervention.

Finally, a summary of the results of the study is given, with a discussion of these results informed by the literature described in Chapter 2. The limitations of this study are discussed and suggestions for future study are put forward.

4.1 The problematic concepts in physics

Many students find physics to be a difficult subject, possibly because the Newtonian physics that is taught at high school is often in conflict with students' real world experiences (Nersessian, 1989). Students are often able to manipulate symbols and formulae, but lack a real understanding of the underlying concepts, as described in Section 2.3. This can be understood as a lack of connection between the symbolic domain and the concrete domain (Greeno, 1989). Students are often unable to translate a problem from one domain to another. An awareness of these four domains as proposed by Greeno (1989), which are inherent in problem-solving, may prompt us to encourage students to make the connections between the domains and translate comfortably between them. These translations are initially difficult and require practice to make them easier as schema are acquired.

Johnstone (2009) used a triangle to represent the three ways in which chemical phenomena can be described. If this triangle is modified from its application in chemistry, the representations of a physics problem can be imagined on the vertices of a triangle: physical and contextual, conceptual and abstract and symbolic and mathematical. Any problem might fall somewhere in the triangle, with its representation being more mathematical or more conceptual or somewhere in between. Experts can easily move about within the triangle from one representation to another, but students may struggle to follow a teacher who moves about within the triangle in their explanations, as this results in significant cognitive load (Johnstone, 2009).

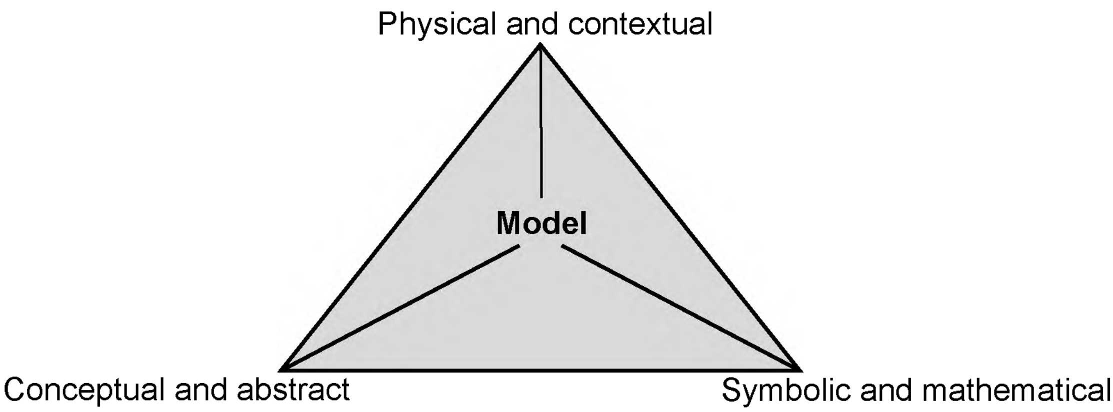


Figure 4.1: *Four representations of a physics problem*

For example, a teacher who describes a rocket being fired vertically by an engine (physical or contextual domains) and states that Newton's second law can be used to calculate the acceleration of the rocket if the relevant forces are known (conceptual or abstract domains) and then writes a formula on the board to perform the calculation (symbolic or mathematical domains) is moving between the vertices of the triangle. By placing the model representation in the centre of the triangle, translations from one representation (Greeno's 'domain') to another become more manageable for a novice problem solver. If the teacher drew a sketch and / or a free-body diagram of the scenario, the student would find the transitions between representations easier. Students should be encouraged to draw diagrams for themselves as this enhances understanding and assists with connecting the domains and moving between them.

4.2 Identification of Problem Topics

In order to choose the topic for intervention, a number of data sources were studied, as described in the Method (Section 3.4.1). The relevant summaries of this data are given below.

The National Department of Basic Education (DBE) and the Independent Examination Board (IEB) publish feedback on the National Senior Certificate (NSC) examination. I used the feedback to establish which topics students across the country score poorly on or struggle with most often. Figure 4.2 shows the years in which each topic was mentioned in the reports and the years in which the average score for questions on a topic was below 50%.

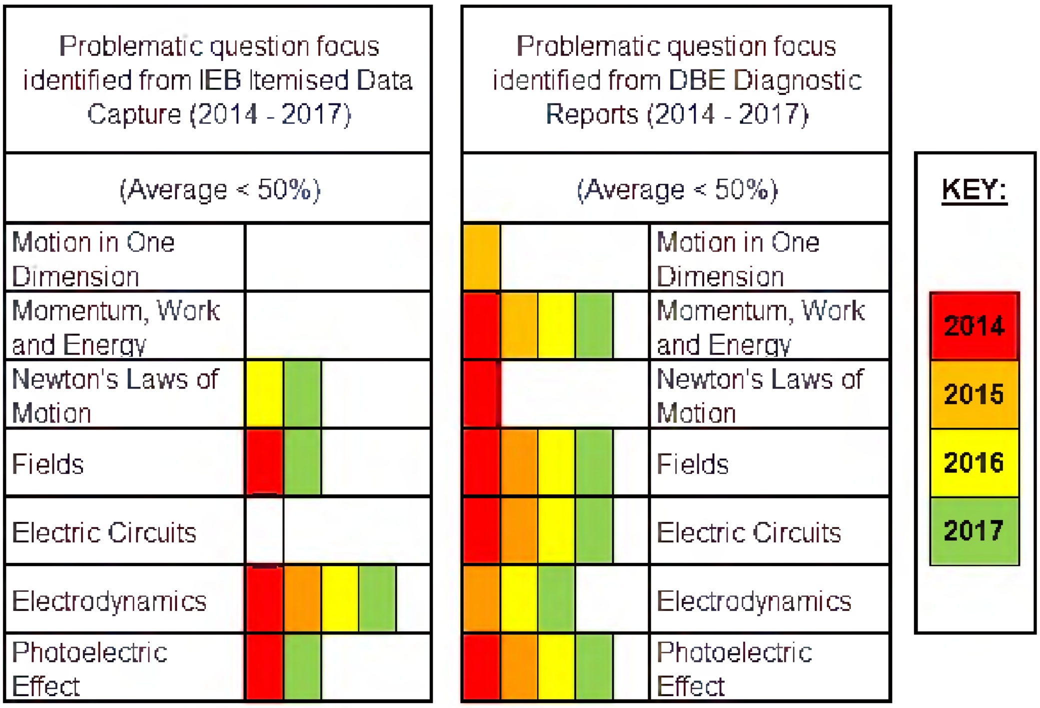


Figure 4.2: *Prevalence of problematic concepts in the 2014 - 2017 IEB and the DBE NSC.*

Figure 4.2 indicates that Momentum, Work and Energy, Fields, Electric Circuits, Electrodynamics and Photoelectric Effect are all regularly problematic in the DBE examinations, while Electrodynamics is most problematic in the IEB examinations.

In contrast to the concepts flagged nationally by the DBE and IEB reports, the Itemised Data Capture (IDC) reports provided by the IEB for The Schools indicated that students at The Schools most frequently find Newton’s laws of motion most frequently problematic (Figure 4.3).

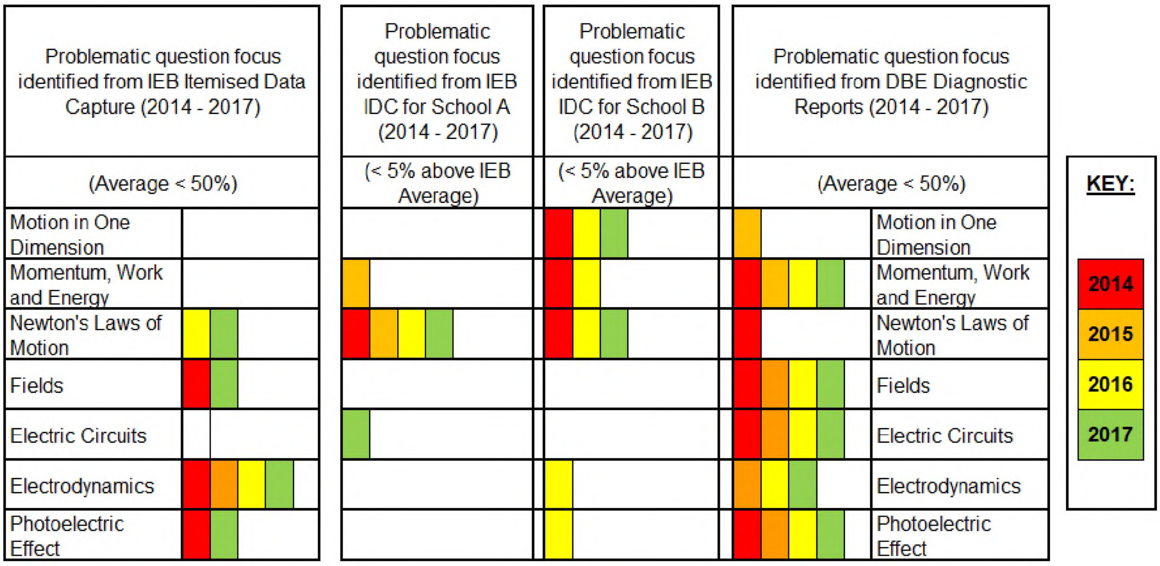


Figure 4.3: *Prevalence of problematic concepts in the 2014 – 2017 Grade 12 final examination results of The Schools (inner columns) compared to the IEB and the DBE NSC (outer columns).*

From the historically collected data from 2012 – 2017, the topics of forces in two dimensions, circuits and electrodynamics had the lowest average marks (Figure 4.4). We cover circuits and electrodynamics in Grade 12, which would have limited the sample of students that I could use for my study. The topic of forces in two dimensions is taught in Grade 11 and examined in Grade 11 and Grade 12, which allowed me to test 3 cohorts of students: the Grade 11 and Grade 12 groups in 2018 and the Grade 11 group in 2019.

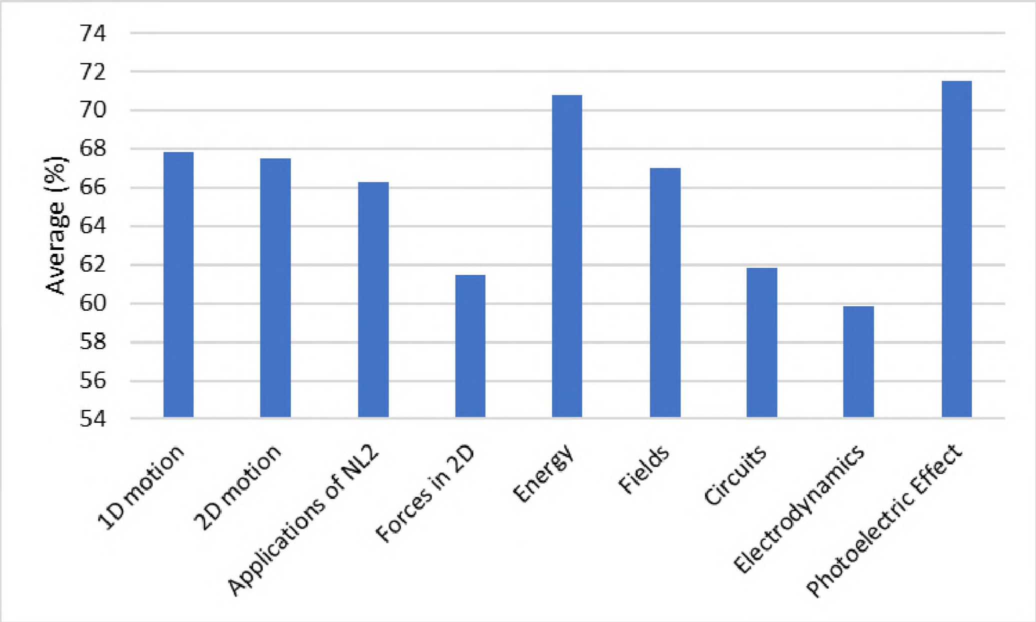


Figure 4.4: *Average marks per topic in Grade 10 – 12 examinations at The Schools between 2012 and 2017.*

The graphs of the average score per question at The Schools in the Grade 12 and Grade 11 mid-year examinations in 2018 (see Figure 4.5 and Figure 4.6 below, respectively), confirmed the trend seen in the IEB IDC analysis above (Figure 4.3), with Newton's laws of motion emerging as a section that is poorly understood.

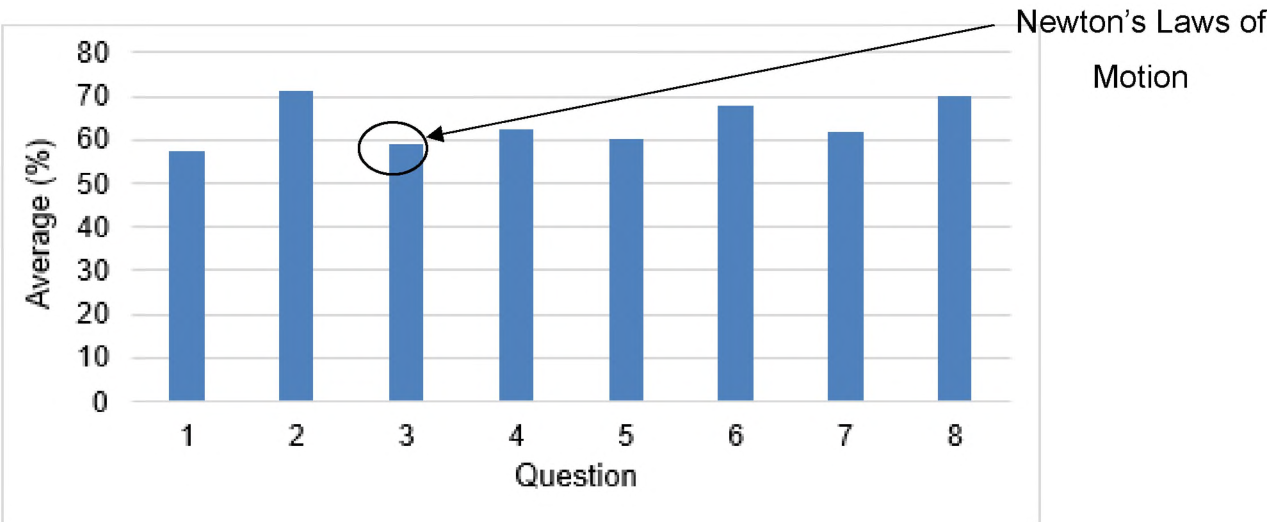


Figure 4.5: *Average percentage for questions 1-8 of the August 2018 Grade 12 physics examination at The Schools (n = 81).*

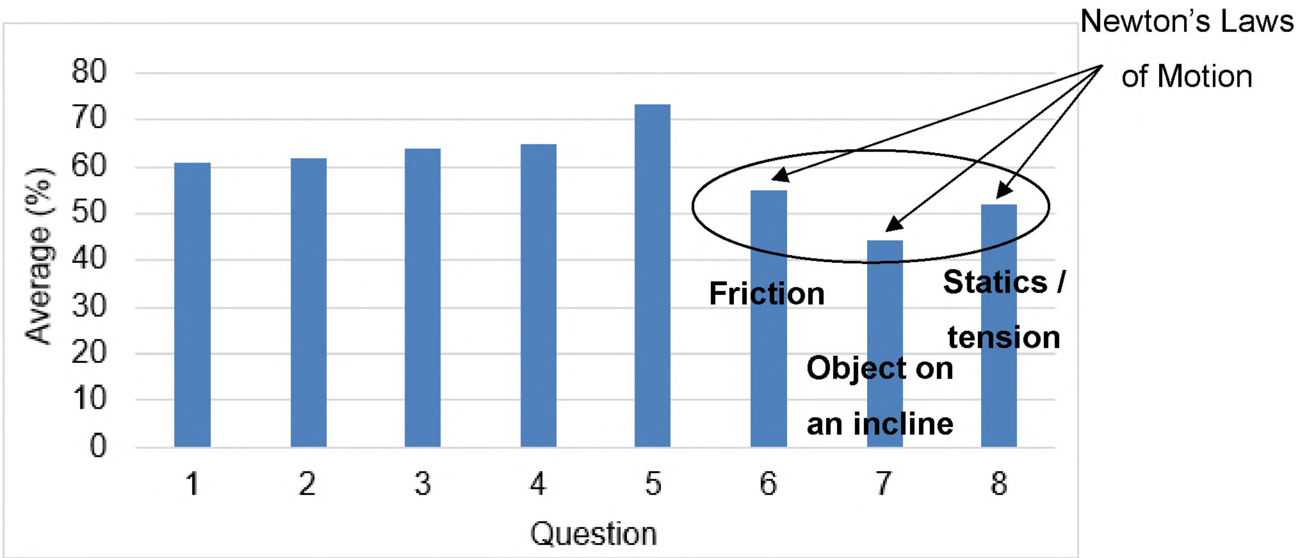


Figure 4.6: *Average percentage for each question 1-8 of the August 2018 Grade 11 physics examination at The Schools (n = 48).*

This was corroborated when I studied the answers to question 3.1 in the Grade 12 August 2018 examinations (see Appendix C). Students were required to draw a free-body diagram of a radio telescope dish on an incline of 20^0 and then (in question 3.4, after some scaffolded questions) to calculate the frictional force acting on the dish. Many students could not correctly include the components of the weight in their free-body diagram or drew them incorrectly (Figure 4.7). Others put the 20^0 angle in the 'wrong place' in their triangle (Figure 4.7). These are common errors that suggest that the student does not understand the mathematics sufficiently and has not practised sufficient routine examples to translate the question into the model domain (a free-body diagram) (Greeno, 1989). Another common conceptual error was to include a force down the incline, which was not always labelled, but sometimes seemed to invoke Newton's third law (Figure 4.8).

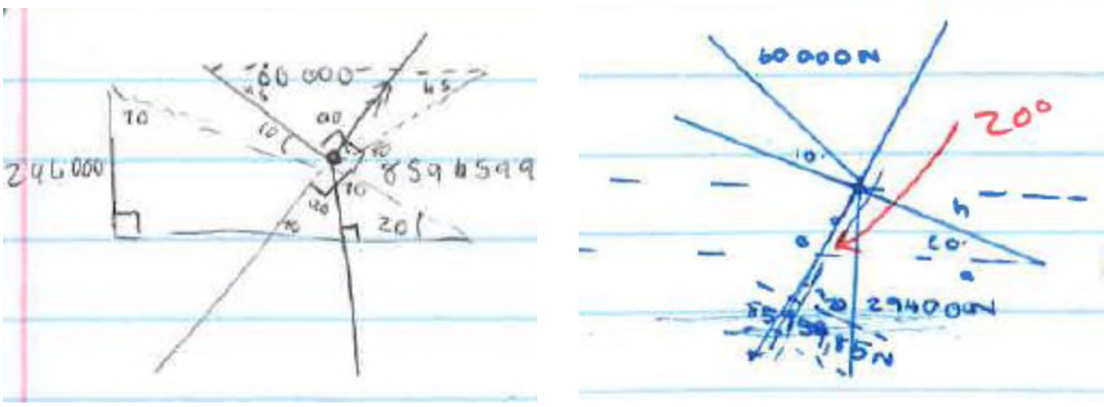


Figure 4.7: *Samples of answers to question 3.1 in the Grade 12 August 2018 examination by students C3209 (left) and C3215 (right)*

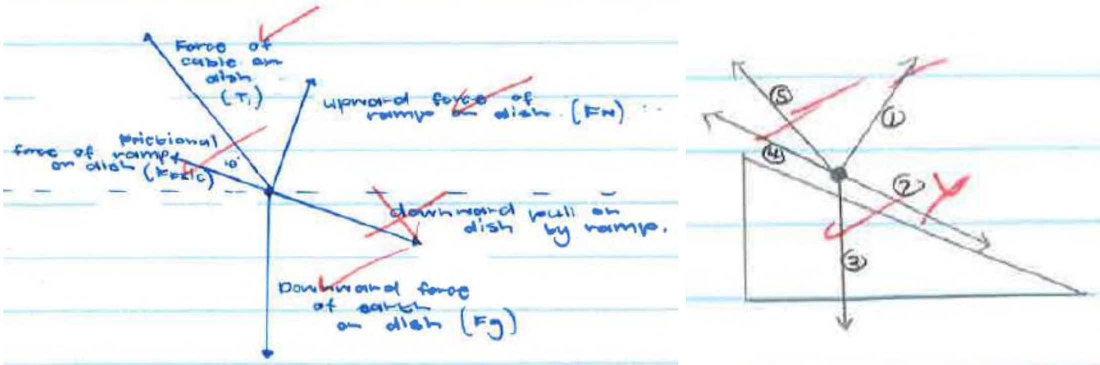


Figure 4.8: *Answers by students C3215 (left) and C4105 (right) illustrating a common error in answering question 3.1 in the Grade 12 August 2018 examination.*

The application of Newton's second law in the mathematical domain was also often not well executed, despite an emphasis on this in the classroom and past papers (see Figure 4.9).

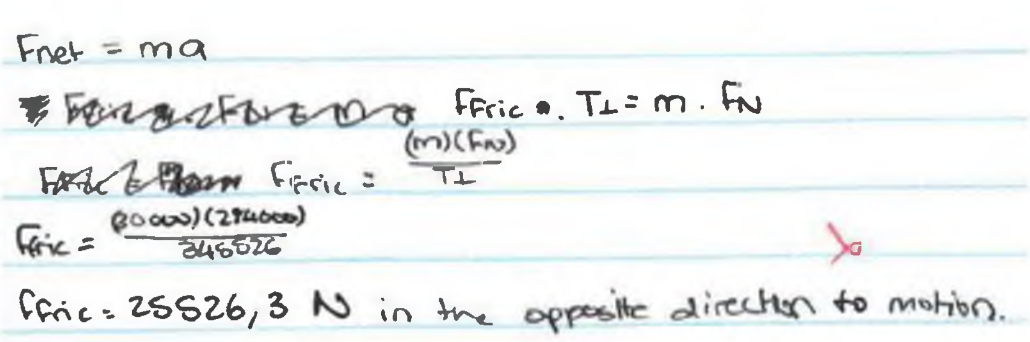


Figure 4.9: *An attempt to answer question 3.4 in the Grade 12 August 2018 examination by student C4105.*

Student answers to Questions 5, 6 and 7 of the Grade 11 August 2018 examinations (Appendix D) also revealed some common errors and misconceptions, particularly regarding free-body diagrams for the forces acting on a trolley resting on an incline (question 6.1). These are illustrated in Figure 4.10, where no force is indicated to maintain equilibrium or prevent the trolley from sliding down the incline; in Figure 4.11, where the frictional force is shown acting *down* the incline, instead of *up* the incline; and in Figure 4.12, where the forces acting on the trolley are incorrectly labelled and the student is unable to determine the perpendicular components of the weight. These students are unable to successfully construct a model from a verbal or pictorial description (Greeno, 1989). Many students only found the component of the weight of the trolley perpendicular to the incline in question 6.2 where they were asked to determine the magnitude of the *perpendicular components* of the weight of the trolley (Figure 4.13). This may be a language issue, but suggests insufficient practise of similar examples, or a lack of self-diagnosis (Section 2.5.10) to realise that both components were required in such a question. Many students did not draw a diagram for question 7 as they were not instructed to.

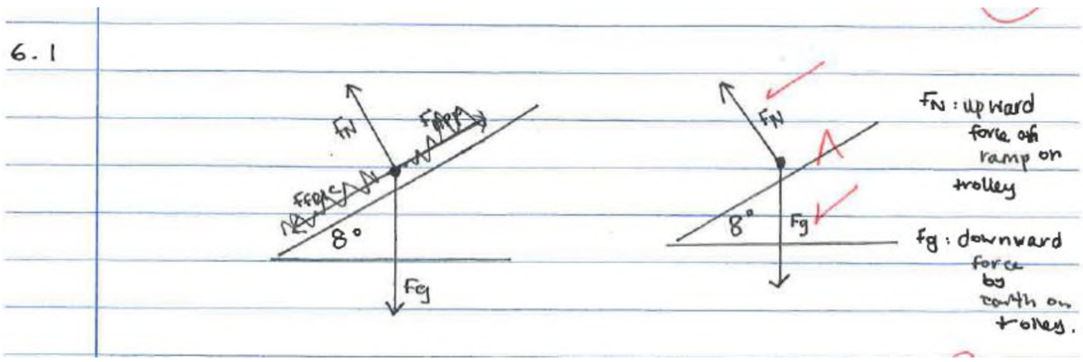


Figure 4.10: *An incomplete free-body diagram drawn to answer question 6.1 in the Grade 11 August 2018 examination.*

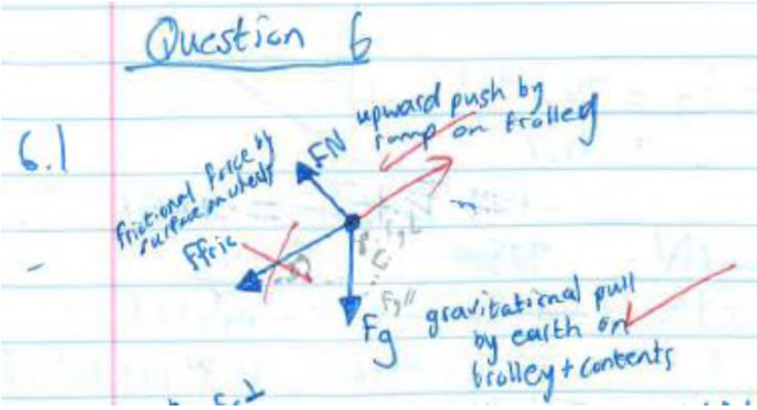


Figure 4.11: *An incorrect free-body diagram drawn to answer question 6.1 in the Grade 11 August 2018 examination.*

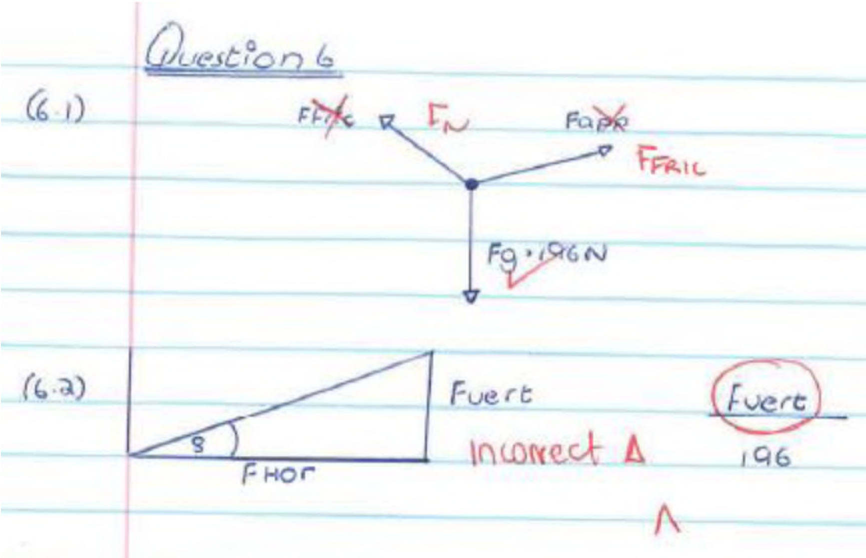


Figure 4.12: *An incorrectly labelled free-body diagram drawn to answer question 6.1 and an incorrect approach to answer question 6.2 in the Grade 11 August 2018 examination.*

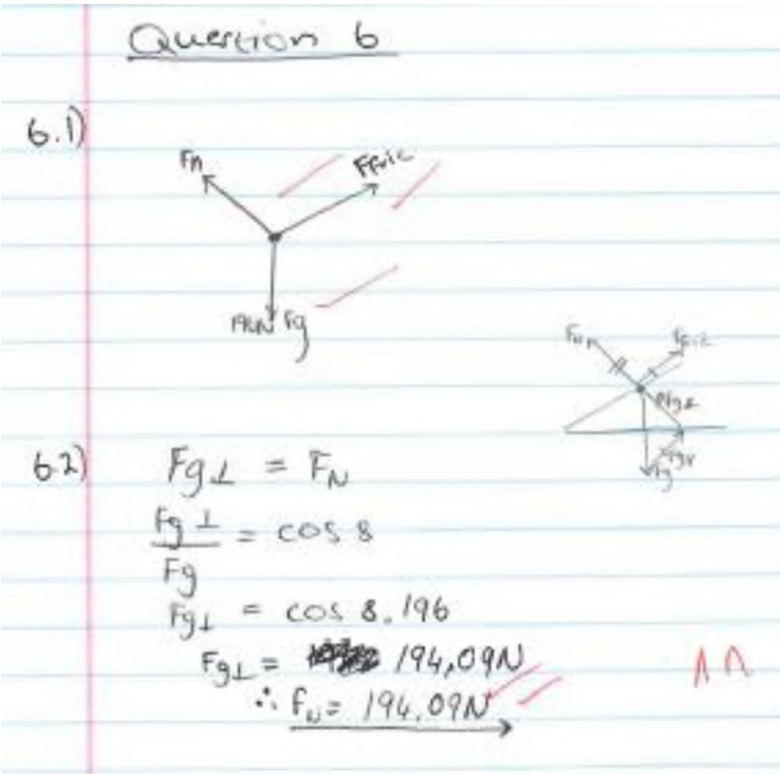


Figure 4.13: *An incomplete answer to question 6.2 in the Grade 11 August 2018 examination.*

4.3 Overview of the findings of all four pre- and post-tests

Table 4.1 summarises the quantitative results of the pre- and post-tests for each intervention and the calculated normalised gain (see Table 3.2 for a summary of the Iterations). The intervention was tested repeatedly to ensure triangulation (Flick, 2018) and the iterative nature of the action-research cycle afforded me the opportunity of improving the resource.

Looking at the change in scores, the intervention of Iteration 4 appears to have been the most effective, with the greatest proportion of students improving their score and no students showing a decreased score on the post-test. However, the intervention of Iteration 3 reported the largest normalised gain. All gains are considerably above 0.3, indicating that the intervention was effective, resulting in students improving their scores by approximately half of the maximum possible improvement.

Table 4.1: *Summary of the quantitative results of each Iteration, based on matched students.*

Iteration	Number of matched students[7]	Unchanged score[8] (pre = 5/5) (%)	Unchanged score[9] (pre ≠ 5/5) (%)	Improved score (%)	Decreased score (%)	Normalised gain <g>
1	13	30.8	0.0	53.8	15.4	0.519
2	28	17.9	10.7	67.9	3.6	0.463
3	20	20.0	10.0	65.0	5.0	0.558
4	20	0.0	30.0	70.0	0.0	0.525

An improvement in the pre- to post-test score indicates that the intervention was successful (Li and Singh, 2017). This suggests that the students' understanding of Newton's second law was improved by their use of the

[7] Matched students completed both the pre-and post-test
[8] The pre-test and post-test scores were the same (5/5)
[9] The pre-test and post-test scores were the same, but the pretest was not 5/5

resource, as the questions in the pre- and post-tests tested their understanding of key concepts related to the application of Newton's second law. The reason for the success of the intervention cannot be attributed to one factor. It is most likely the result of the cumulative effect of strategies to improve learning, such as the application of theory of cognitive apprenticeship in the design, the repetition of examples to support schema acquisition and to reduce cognitive load, the use of multiple representations and encouraging self-diagnosis. Subsequent test and examination questions on this topic tested the transfer of understanding to other problems. The emphasis of the resources was largely on the quantitative aspect of Newton's second law, although the pre- and post-tests assessed qualitative understanding. The exposure to quantitative examples could be a reason for the reported improvement shown in the students' qualitative understanding (Section 2.5.11) (Singh, 2008a).

In addition to the quantitative analysis of results, I examined the test and examination scripts in a qualitative analysis, looking specifically at the diagrams and representations made by students.

Drawing diagrams and using alternative representations does not come naturally to students and, as described in Section 2.5.7.1, many students resist drawing diagrams. This approach should be modelled by teachers and learning resources (as described by the theory of cognitive apprenticeship: Section 2.2.3 (Collins, Brown and Newman, 1987)) to encourage and entrench the habit of using multiple representations (Section 2.5.7.2), by recognising their importance in developing and deepening understanding.

Maries and Singh (2017) found that there is a link between the quality of the diagrams that students draw and their performance in problem-solving. While this skill can be developed through practice and through coaching, some students begin with a better-quality diagram, which may be because these students have a certain initial level of understanding and competency to draw a better diagram. The rubric (Table 3.4) was used to assess the quality of the diagrams produced by students in the test of transfer for each iteration (except Iteration 1, which was externally assessed).

4.4 Findings and discussion of each intervention

Each intervention was slightly different and so the specific results for each Iteration is reported separately. As the purpose of this study was to assess whether an intervention could be effective, the results report the average performance and look at trends, although success could be seen as an improvement for an individual.

4.4.1 Iteration 1: Grade 12 Revision Camp, September 2018

The answers given in response to the pre- and post-tests by the Grade 12 group who attended the Revision Camp session focussing on this resource are shown in Figure 4.14. The outlined columns indicate the correct option for each question. The developed resource appeared to decrease the prevalent misconceptions, as the number of students answering incorrect options decreased in all five questions after the students had worked through the intervention. In questions 2 – 5 the number of incorrect options answered was also reduced after the intervention.

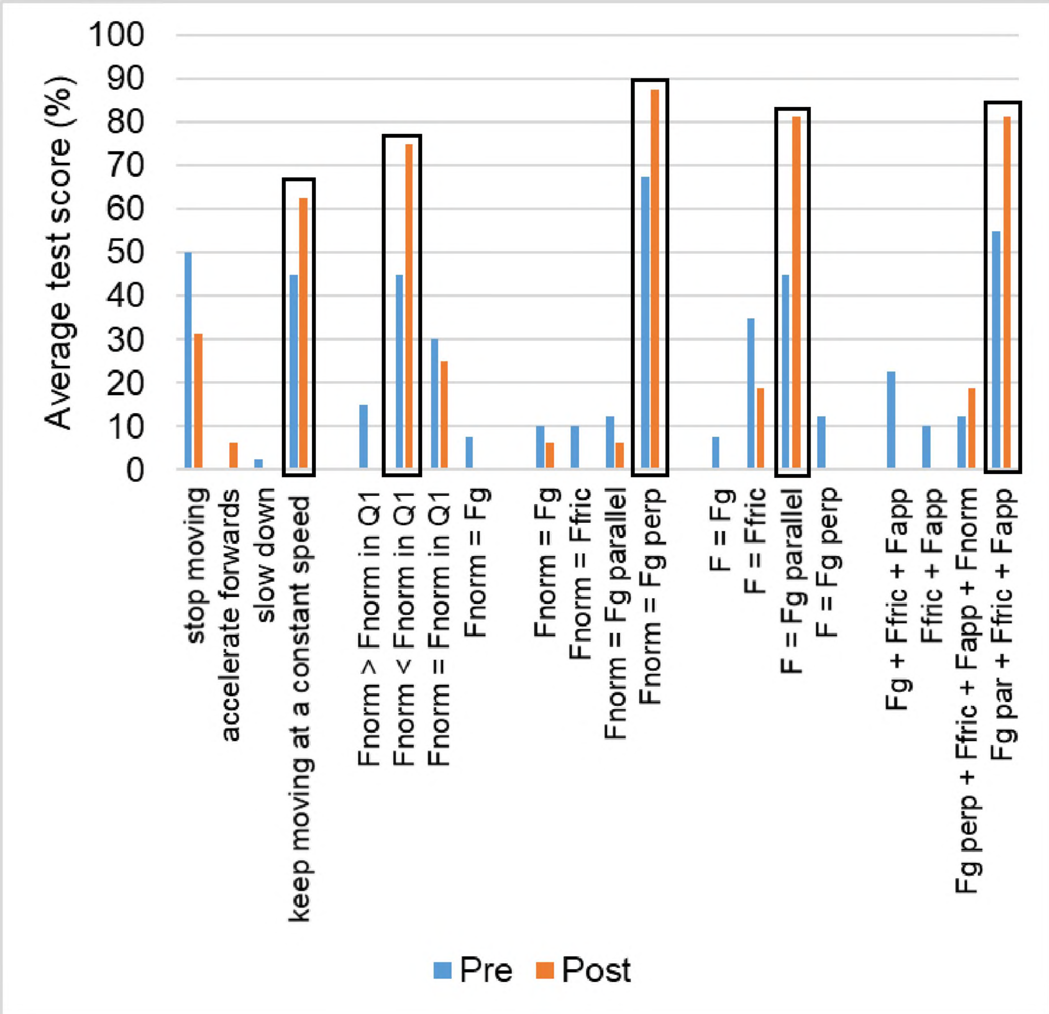


Figure 4.14: *Multiple choice responses for questions 1-5 in the pre- and post-tests administered to the 2018 Grade 12 group at The Schools.*

Question 1 retained a large proportion of incorrect answers (stop moving) after the students had worked through the resource. This suggests that students did not understand that even when there is no net force, an object can continue at a constant velocity, provided it had some initial velocity. A common misconception is that when there is no net force there is no *velocity*, rather than no *acceleration*. As mentioned in Section 2.3, this is an Aristotelian view that persists even today.

The normalised gain for this iteration was 0.519, suggesting a moderate gain (Hake, 1998), as students improved their score by half. The results of the pre-test (n = 40, M = 2.6, SD = 2.9) and the post-test (n = 16, M = 3.9, SD = 2.5) indicated that there was a significant improvement in scores, as shown by a t-test with p = .005 (p < .05).

1. A box is being pulled along a rough horizontal surface using a rope, as shown in the diagram alongside. If the frictional force is equal to the force that is applied by the rope, the box will

- ☐ stop moving
- ☐ accelerate forwards
- ☐ slow down
- ☐ keep moving at a constant speed.

Figure 4.15: *Question 1 from the pre- and post-test to ascertain students' understand of Newton's second law.*

Only 20% of the sample group completed the post-test, which suggests that not all students worked through the intervention resource, which was given to all Grade 12 students, but introduced at a voluntary Revision Camp. Verbal feedback also suggested that, because the pre-test and the post-test were very similar, some students thought that they had the wrong form when they accessed the post-test form online and did not answer the questions again.

In interviews conducted after they had worked through the resource, students were asked whether the resource was helpful to them and, if they felt it was, why. The answers given by the students were all positive, which prompted my future use of evaluation forms, which could be returned anonymously, in case students were reluctant to give me negative feedback in person. This could be due to the power dynamic that I tried to reduce in my introduction of the study, but is often more pronounced in one-on-one situations. I did interview a pair of students together and they were relaxed in the interview, but still not critical of the resource.

Students' feedback on the resource in response to the interview question are given below, with some commentary on each:

> *"It gives a different perspective on doing harder questions so that when it comes to the exam it will be easier for us to do." (Student C4111)*

This suggests that the student recognises that scaffolded questions (theory of cognitive apprenticeship, (Collins, Brown and Newman, 1987)) help them reach a level where they can handle more difficult questions (with more schemas available, (Sweller and Chandler, 1991)) and then transfer their understanding to new contexts.

> *"It made me understand the concept of like equilibrium and moving force and accelerating force a lot better. I think that was the thing I was like essentially missing was like the first basic principles and once I got that then everything else fell into place a lot easier." and "everything was like pretty um self-… not self-explanatory, but like step-by-step guiding and you just had to apply that the in-depth questions." (Student C221)*

This student benefitted from the structure of the resource, which assisted with building a knowledge structure (Section 2.5.1), which allowed them to file schema appropriately.

> *"I found that the lesson that you taught, um, with the handout was helpful. So, if you had given me the revision booklet, ah, revision booklet without the lesson first, I wouldn't have been able to match that together. So, having the lesson and the revision booklet together was very helpful for me." (Student C3214)*

The response in this interview articulates the problem with the resource provided in Iteration 1: it was not ready for students to use independently. The modelling that I did on the board needed to be put into the resource.

The group of students involved in Iteration 1 wrote their final IEB NSC examination two months after the intervention. Question 4 in the IEB examination, examined the application of Newton's second law (Appendix G). This was amongst the worst scoring questions at The Schools, with School A's result for this question 5% lower than the IEB average (see Figure 4.16) and School B's result 2% above the IEB average, while all School B's averages for the other questions were well above the IEB average (see Figure 4.17).

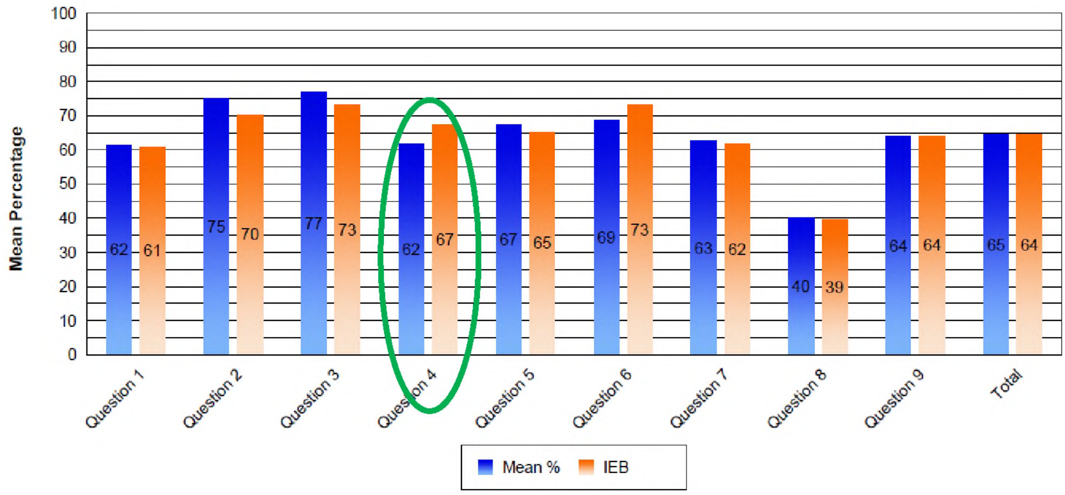


Figure 4.16: *Comparison of School A's results (Mean %) with the IEB average in the 2018 IEB NSC examination, reported per question*[10]

[10] (Independent Examinations Board, 2018)

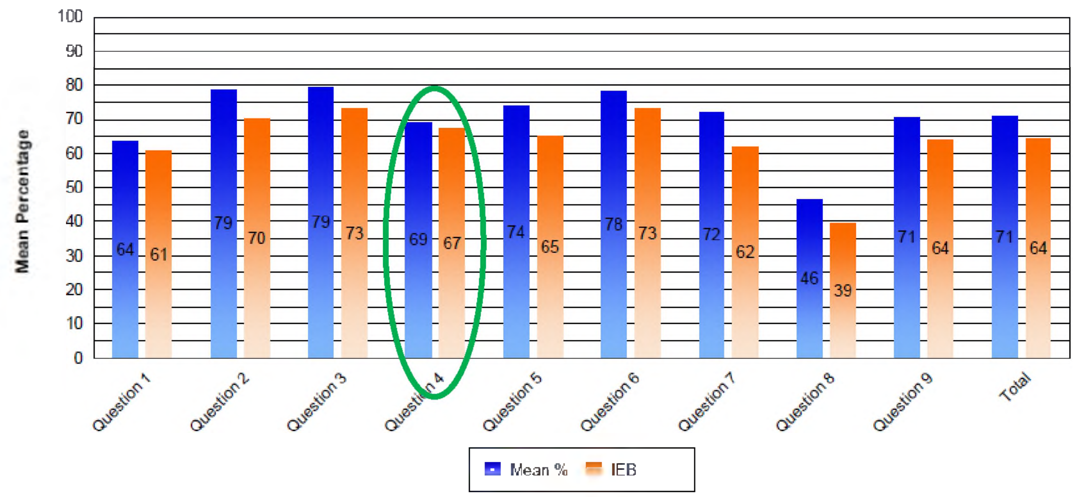


Figure 4.17: *Comparison of School B's results (Mean %) with the IEB average in the 2018 IEB NSC examination, reported per question*[11]

While this suggests that the intervention was ineffective, the results should be given some context. The graphs give the results of the entire student group and, as previously stated, it is likely that many students did not work through the resource. In addition, the Physical Sciences results of The Schools on the IEB examination overall were significantly worse than previous years (see Figure 4.18), particularly for School A.

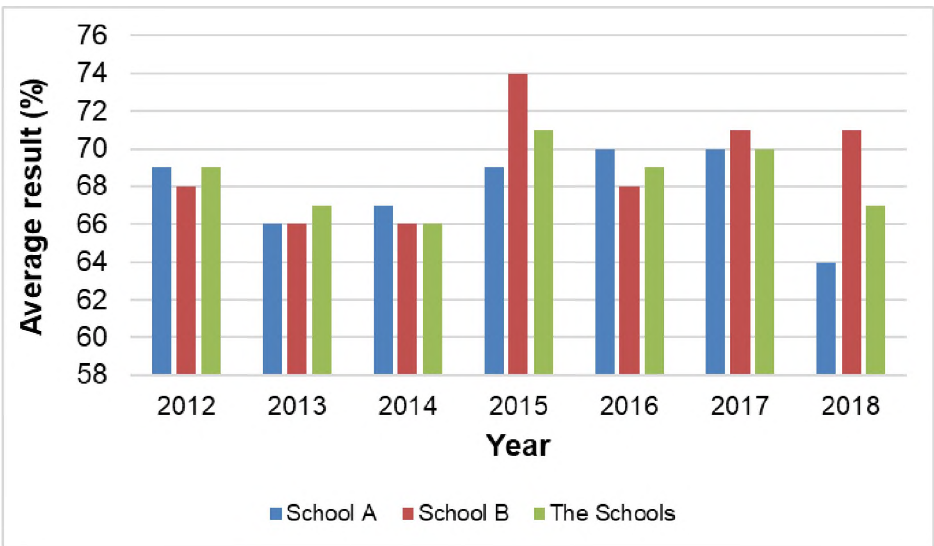


Figure 4.18: *Average scores in the final IEB NSC Physical Sciences examinations for The Schools from 2012 to 2018.*

[11] (Independent Examinations Board, 2018)

4.4.2 Iteration 2: Grade 11 Revision, October 2018

The intervention was adjusted for the Grade 11 group to include more worked examples. This group used class time to work through the resource, without a specific lesson explaining the concepts. However, a large amount of teacher input and structuring was needed in class. The resource was well-received by the students, as is evident from the evaluation, but it took a lot of class time and could not be used effectively independently.

There was an improvement in the scores on the post-test following the use of the resource by the Grade 11 2018 group (as shown in Figure 4.19). However, the misconception regarding an object in equilibrium, tested by question 1 and described in the previous Iteration (4.4.1), was even more prevalent.

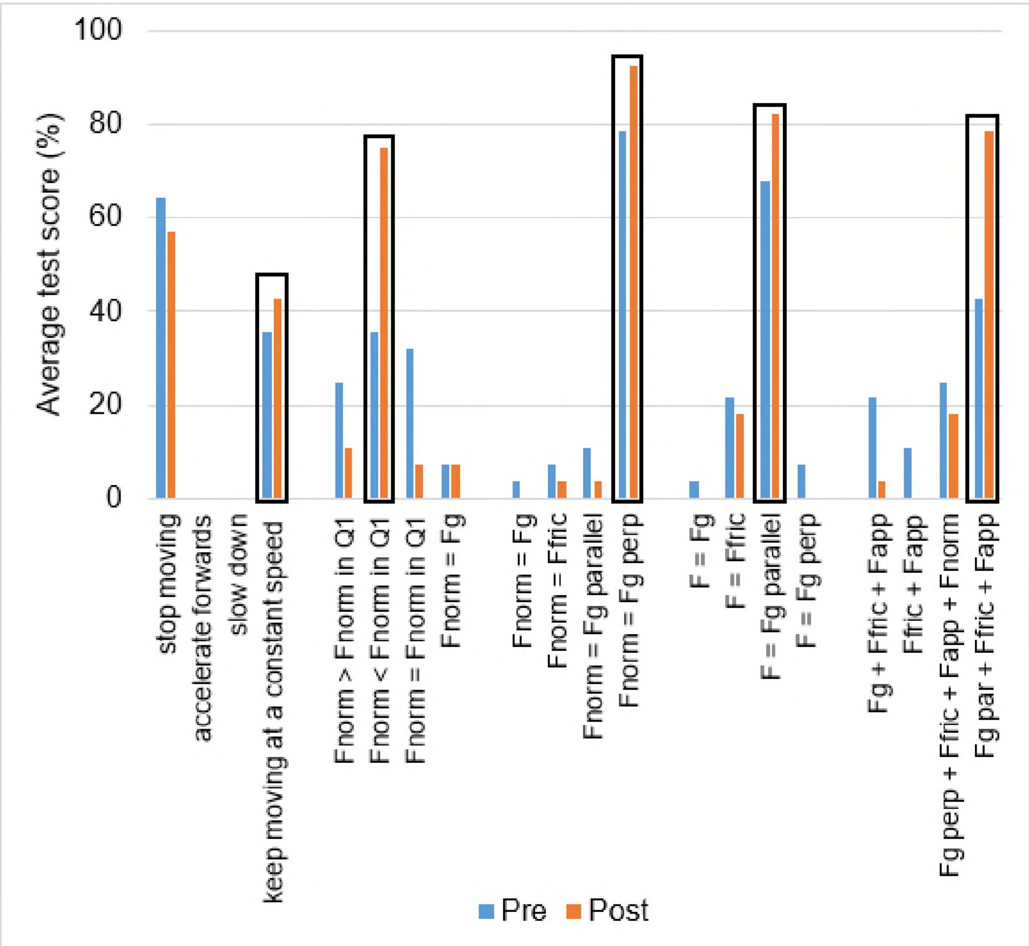


Figure 4.19: *Multiple choice responses for questions 1-5 in the pre- and post-tests administered to the Grade 11 group at The Schools.*

As described in Section 3.4.5.3, closer scrutiny of the Grade 11 2018 resource revealed that the behaviour of an object experiencing forces in equilibrium had not been sufficiently covered and such examples were explicitly addressed in the resource that was evaluated in Iterations 3 and 4.

The normalised gain for this iteration was 0.463. Although this is less than Iteration 1, it is still considered a moderate gain (Hake, 1998), as students improved their score by just less than half. The results of the pre-test (n = 28, M = 2.6, SD = 2.5) and the post-test (n = 28, M = 3.7, SD = 1.8) indicated that there was a significant improvement in scores, according to a t-test (p = .003).

Most of the comments from students on their evaluation forms were positive, saying that the booklet was *"useful"* (students B2207, B2202 and B2105) or "helpful but difficult" (student B2211).

Some offered more comment, such as

> *"found booklet very helpful and going to use it to study this section!" (student B2119)*

and

> *"The step by step way of learning is helpful." (student B2207).*

This last comment suggests that the resource helped the student with their construction of a knowledge structure (Section 2.5.1) or perhaps that the scaffolded questions and annotated diagrams (theory of cognitive apprenticeship and worked examples) were helpful.

The only negative comment was

> *"I'm still confused ma'am. Could we please do more booklets." (student B2213),*

which suggests that the student believes that a booklet could be a useful resource.

A student commented

> *"I was seeing the same thing over and over again so it eventually became a lot easier because I had seen it so much and knew what to do"*

which supports the theory of schema acquisition through repetition (Larkin et al., 1980) (2.1.6 and 2.2.2). The same student suggests that the resource could be improved by

> *"[m]ore variety of questions"*

which resonates with the idea that exposure to a large number of questions may not improve problem-solving skill (Sweller and Cooper, 1985), but it does result in schema acquisition (Larkin et al., 1980; Sweller, 1988).

The performance of the Grade 11 students in the relevant questions in the November 2018 examination showed some improvement (see Appendix G for questions). The MCQs 1.3, 1.4 and 1.5 tested the application of Newton's laws, and analysis of the student responses to the examination questions all showed more correct responses than incorrect responses, indicating good general understanding of the concepts tested (see Figure 4.20).

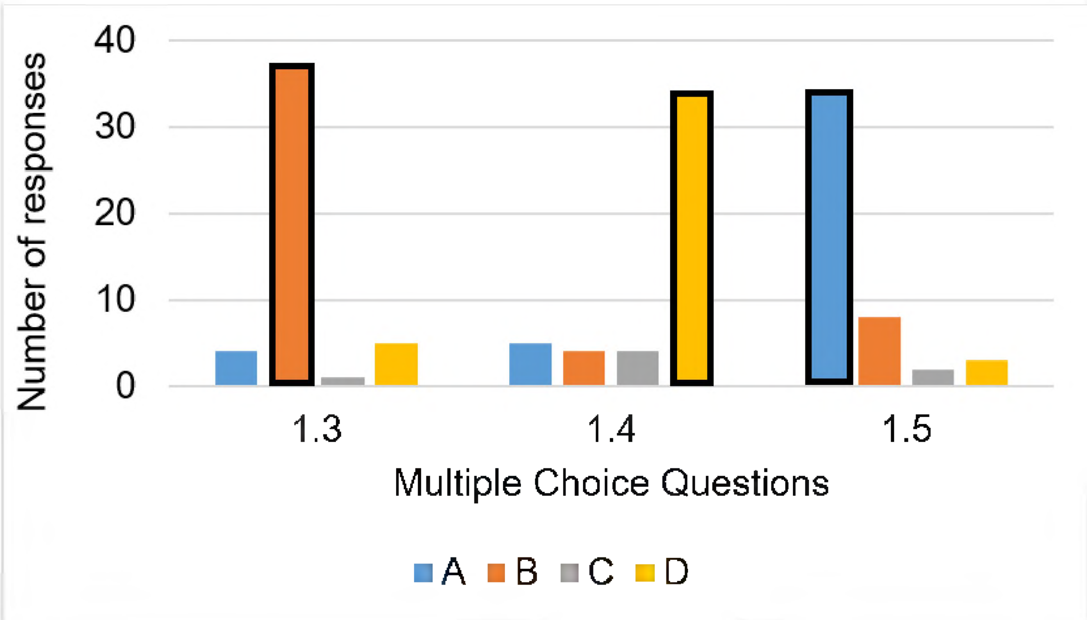


Figure 4.20: *Grade 11 participants' responses to questions 1.3 – 1.5 in the November 2018 examination at The Schools (n = 48).*

The 2018 Grade 11 group also showed an improvement in the long questions focussing on the application of Newton's second law in their November examinations (Questions 4 and 5) (Appendix H). Despite Question 5 being a cognitively demanding question, the average performance by students in this question was better than in questions on the same topic in the August 2018 examination.

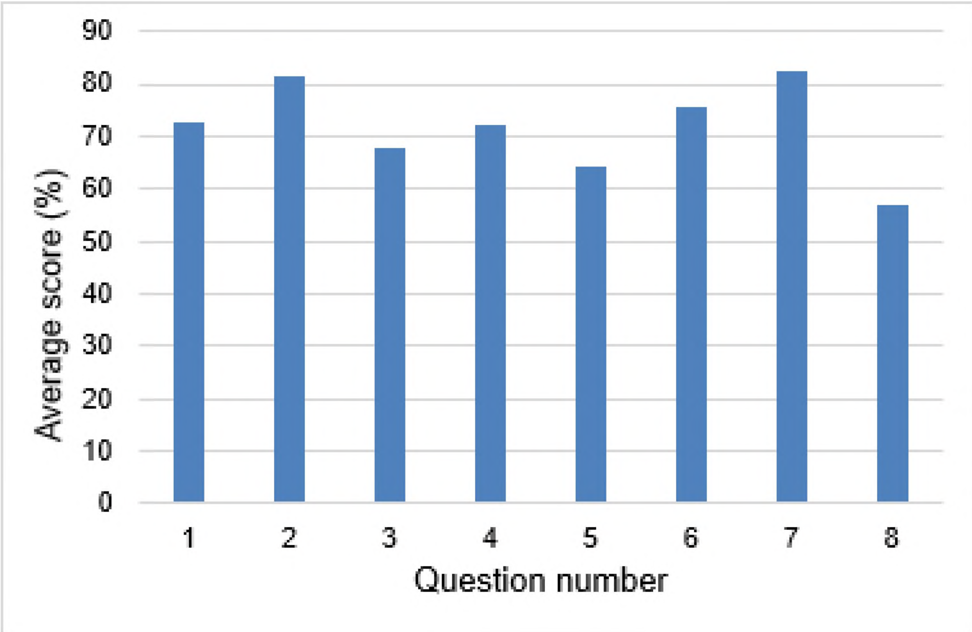


Figure 4.21: *Average score in each question in the Grade 11 November 2018 examination (n = 48).*

Having realised the importance of mental models and drawing diagrams through my engagement with literature, I took note of students' use of diagrams in their answers in the Grade 11 November 2018 examination. There was an improvement in the quality of the diagrams that the students drew (see Figure 4.22 below). The quality of the diagrams was assessed by the rubric given in Table 3.4. As the intervention had been used in class, there is greater certainty that all students had worked through it.

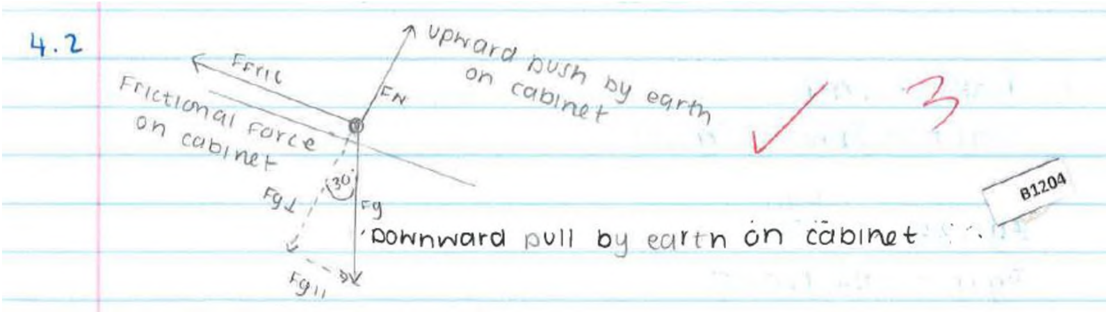


Figure 4.22: *An answer provided in the Grade 11 November 2018 examination.*

In question 4 (Appendix G), 48% of students drew additional diagrams (without being instructed to draw a diagram). This may be because question 4 involved an incline, which had been a focus of the resource. Figure 4.23 below shows an answer given by a student in question 4 who resolved a force into its components, even though this was not necessary to solve the problem, which suggests that in some cases the students were applying a method without really understanding the reason or purpose of the approach.

In question 5, only 4% of students drew additional diagrams. Students may have drawn over the diagram provided on the question paper, rather than on their answer scripts and I only studied their answer scripts. Question 5 was cognitively demanding and unlike previous questions that students had practised.

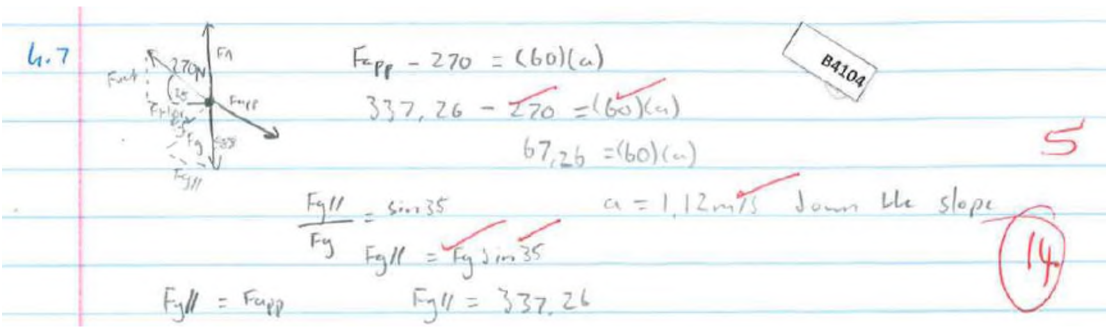


Figure 4.23: *An answer provided for question 4.7 in the Grade 11 November 2018 examination.*

Another unexpected answer was the one shown in Figure 4.24, where a student was unable to draw a correct free-body diagram for question 4.2, but drew the correct diagram to assist them in answering question 4.3. A think-aloud interview just after the student had sat the examination would have been useful here, to gain insight into their reasoning in order to gauge whether this was a careless or unintentional error or a result of a deeper misconception.

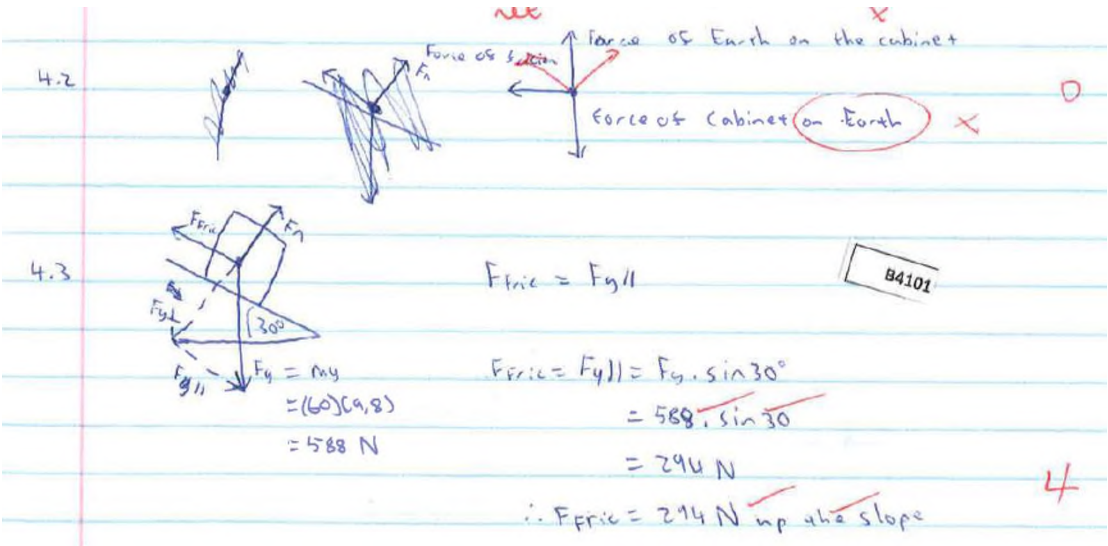


Figure 4.24: *An answer given in the Grade 11 November 2018 physics examination.*

4.4.3 Iteration 3: Grade 12 Examination Revision, August 2019

I prepared an additional section for the Grade 12 group in 2019 to complement the original resource that they had used in Grade 11 in 2018, by addressing equilibrium in more detail. This intervention was intended to coincide with their preparation for the Grade 12 August examinations. I first administered a pre-test to make sure that the misconception (tested by question 1) remained. The group did, indeed, still answer that an object would stop moving when the force applied to it was removed, as shown by the responses in Figure 4.25 below. After working through the resource designed to target misconceptions regarding equilibrium, the number of students choosing the incorrect option for this question was significantly reduced. The incorrect responses for the other questions were also reduced, except for a slight increase in incorrect responses in question 3.

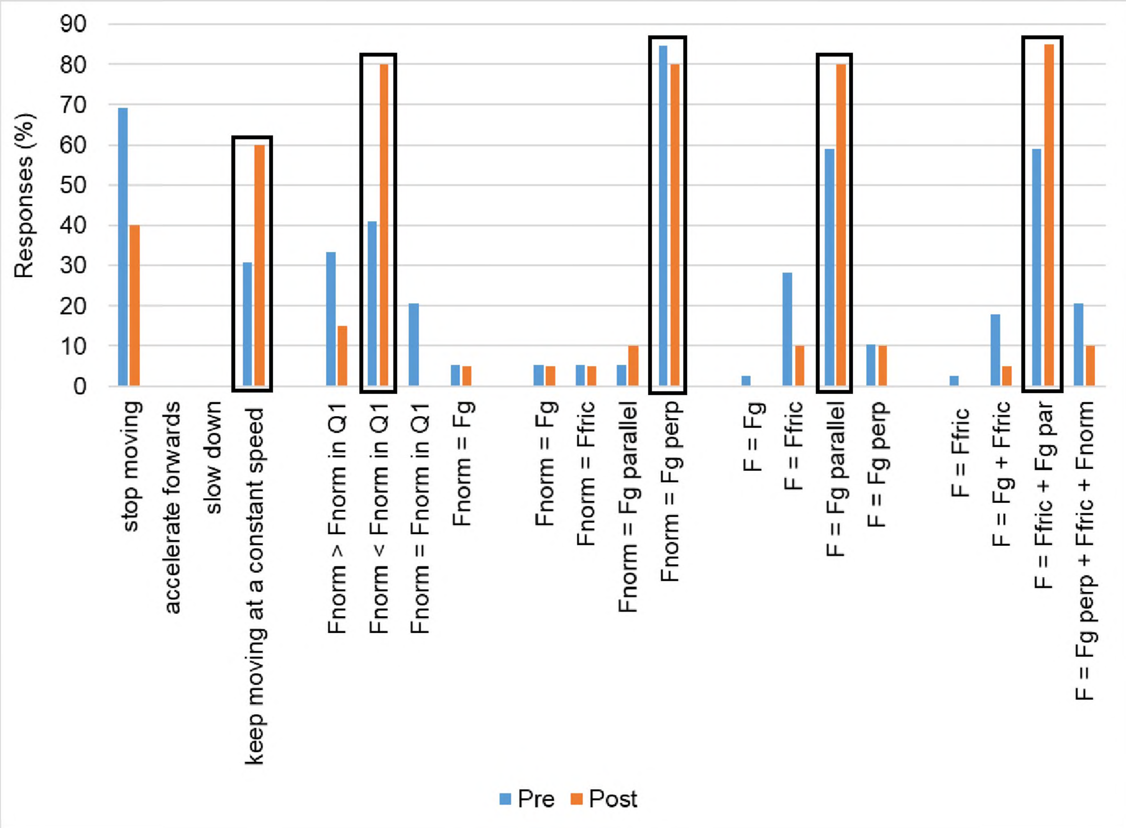


Figure 4.25: *Multiple choice responses for questions 1-5 in the pre-tests administered to the Grade 12 group at School A .*

The normalised gain for this iteration was 0.558, the largest gain of the study, although still considered moderate (Hake, 1998). The results of the pre-test (n = 39, M = 2.7, SD = 2.8) and the post-test (n = 20, M = 3.9, SD = 2.0) indicated that there was a significant improvement in scores, indicated by a t-test with p = .005.

A weakness of my initial design was that I did not know whether students had worked through the resource or not. The fact that a student had completed the post-test and the evaluation form, did not necessarily mean that the student had engaged with the resource. In Iterations 3 and 4, I asked students to indicate (by completing a Google form given in Appendix F.6 and Appendix F.7) whether they had worked through the resource or not and to what extent they had worked through the resource.

39% of this group indicated that they worked through the resource in full, 37% used it in part (looking at the worked examples, but not completing the worksheet), while 10% indicated that they had not used it at all (which is 5 out of the 46 students).

Another t-test analysis compared the *change* from the pre- to the post-test for those who had used the resource (in full or in part) (n = 39, M = 1.5, SD = 1.6) and those who had not used the resource (n = 7, M = 0.3, SD = 1.6) demonstrated a significant improvement for those who used the resource, rather than those that did not (p = .006). The sample of students who indicated that they did not use the resource was very small.

All the feedback provided on their evaluation forms was positive, with special reference made to

- the structure of the resource

  "the summary also helped get my thoughts in order" (student B1216),

- the scaffolding and coaching (theory of cognitive apprenticeship and developing a knowledge structure)

  "doing it step by step [(]rather than a simple memo)" (student B4106)

- the summary nature of the resource, with worked examples (Section 2.5.8), which show modelling (theory of cognitive apprenticeship)

  "a quick crash course." (student B4211)

- the usefulness of modelling (theory of cognitive apprenticeship), as well as reducing the cognitive load on students when they are acquiring schema through problem solving (Sweller, 1988).

  "The examples in the beginning before the work points also helped as a reference." (student B2202).

The MCQ designed to test the students' understanding of Newton's second law applied to an object on an incline was question 1.5, shown below (Figure 4.26).

1.5	A mass is placed on a frictionless slope inclined at 30^0 to the horizontal. The mass is then released. What is its acceleration down the slope? A. 4,9 $m.s^{-2}$ B. 5,7 $m.s^{-2}$ C. 8,5 $m.s^{-2}$ D. 9,8 $m.s^{-2}$

Figure 4.26: *Question 1.5 in the Grade 12 August 2019 physics examination.*

Drawing a diagram or free-body diagram of the forces acting on the mass would have helped students to answer this question. They needed to construct a mathematical statement using the parallel component of the weight to determine the acceleration of the mass. A large proportion of the group incorrectly identified option D as the correct answer, forgetting to take into account that the mass was on an incline.

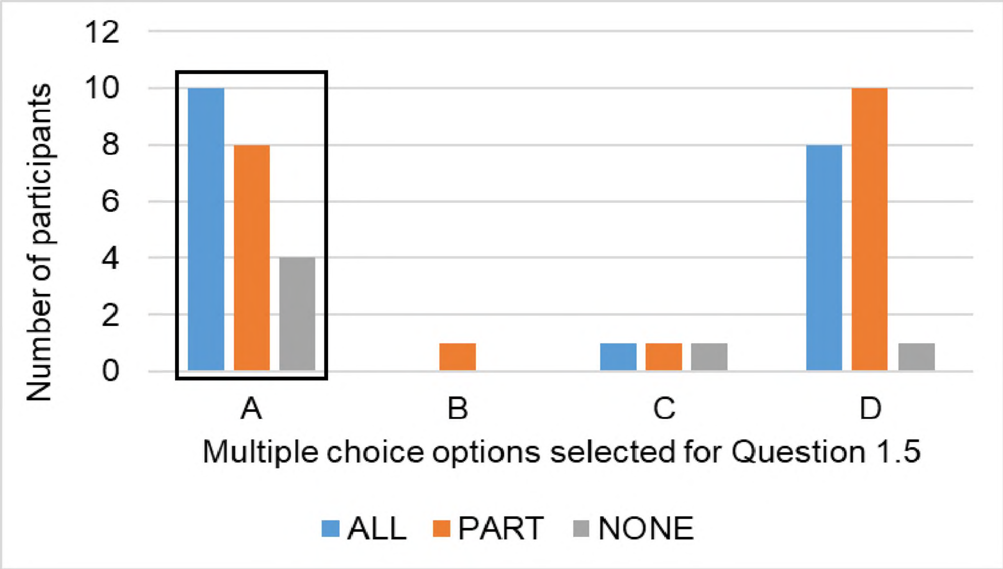


Figure 4.27: *Student responses to Question 1.5 in the Grade 12 August 2019 physics examination at The Schools.*

Question 3 (Appendix I) in the Grade 12 August 2019 examination tested students' understanding of the application of Newton's second law. This question was very similar to the questions provided on the worksheet which accompanied the revision resource on equilibrium (incorporated into Appendix E.3). Unfortunately, Question 3 was still one of the lowest scoring questions in the examination (see Figure 4.28), indicating that this concept remains problematic, despite the intervention.

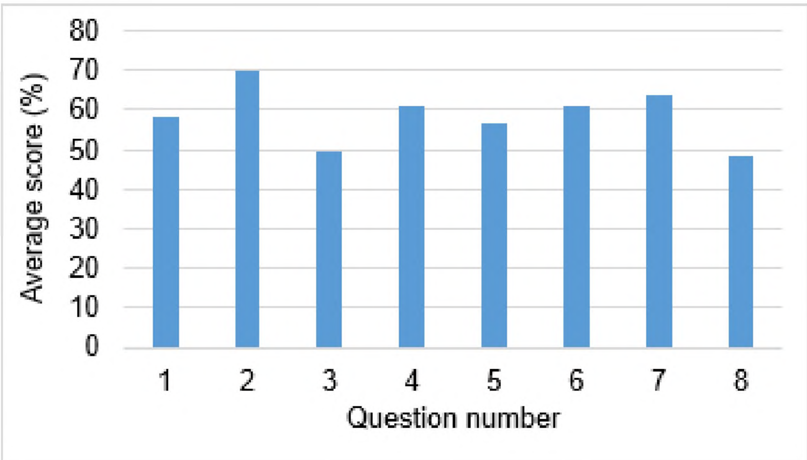


Figure 4.28: *Average score in each question in the Grade 12 August 2019 physics examination (sample size: n = 46).*

Figure 4.29 shows the average scores for the groups who worked through the resource in full, in part or not at all and the results suggest that working through the resource allowed the students to achieve better results on question 3. It must be noted that the resource is probably not the only factor influencing the students' results. Students who worked through the resource might generally be more diligent and may also have practised a large number of past papers or be better able to revise effectively or have a better initial understanding of the concepts. Similarly, those who chose not to work through the resource may have felt that they understood the work already and so may not have seen the need to engage with the resource. This is an example of where specific interviews may have brought to light the students' perceptions and reasons for not engaging with the resource (few students who did not use the resource completed the evaluation form).

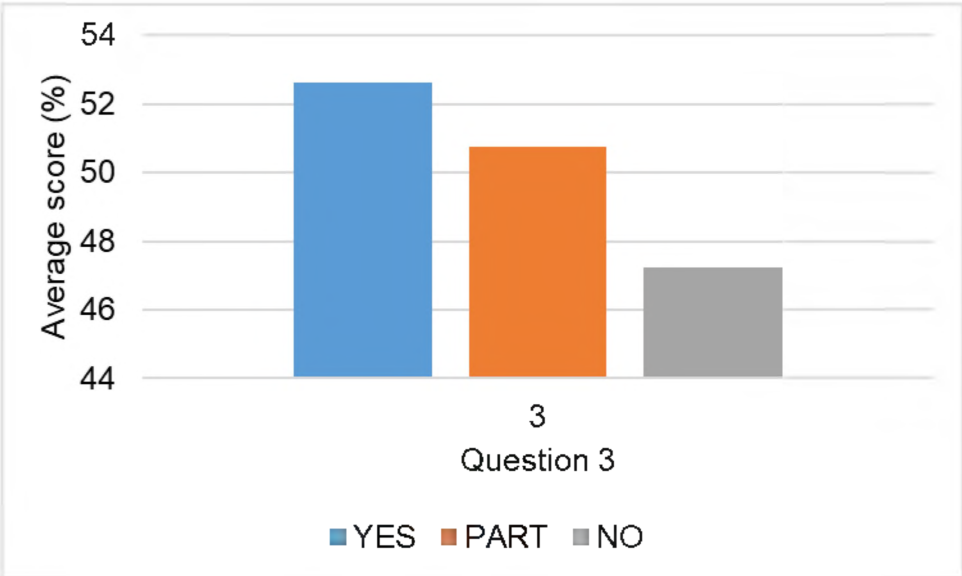


Figure 4.29: *Average score in question 3 in the Grade 12 August 2019 examination for the groups who made use of the resource fully (n = 20), partially (n = 19) or not at all (n = 7).*

Only seven students responded that they did not engage with the resource, meaning that this average is easily affected by a single result. In the sample of five students who did not engage with the resource, one achieved 92% for the question (this student is consistently a top achiever and is able to understand concepts without much additional help) and one did not attempt the question at all. Removing both of these outliers only changes the average by 1% (to 48%) and so I have left them in the sample.

In answering Question 3 in the examination, 26% of students drew one or more additional diagram (without being instructed to draw a diagram to answer the question). When analysing the quality of the diagrams used with the rubric (Table 3.4) the average score for the diagrams of those students who completed the resource in full was 5% higher than those who completed it in part. I could not compare those who completed it with those who did not complete the resource because class time was used for the resource and so the whole grade had completed at least part of the resource. An example of a diagram that scored full marks on the rubric is given in Figure 4.30 and was provided by a student who had worked through the entire resource.

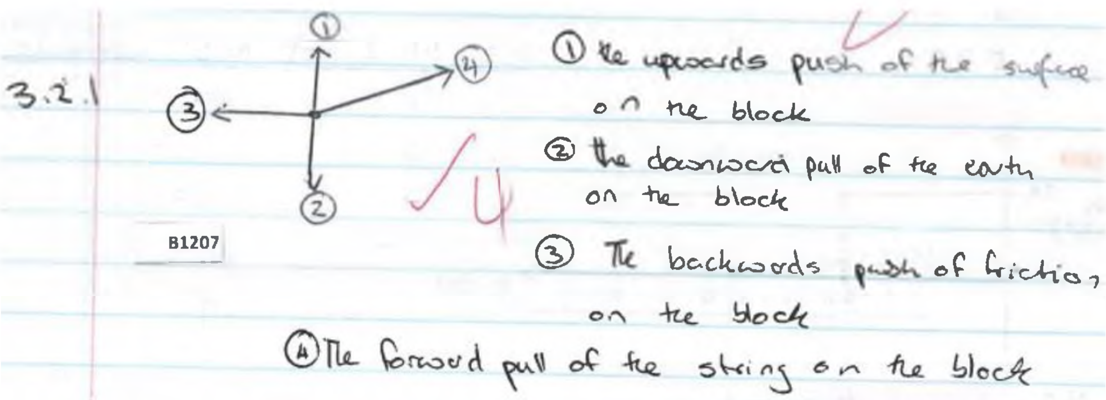


Figure 4.30: *Answer provided to question 3.2.1 in the Grade 12 August 2019 examination at The Schools.*

Many students drew the normal force with equal (or longer) length to the gravitational force or weight of the object, although a force was applied at an angle upwards to the object. An example of such an answer is shown in Figure 4.31.

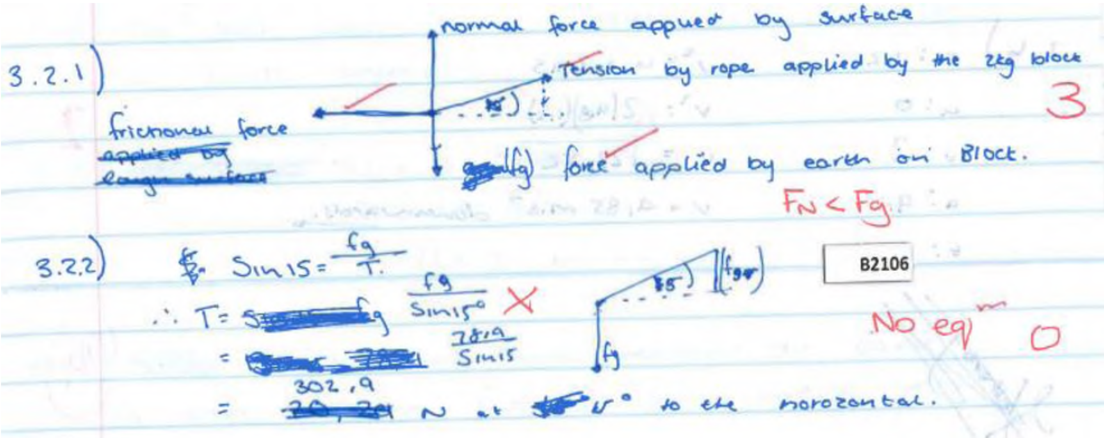


Figure 4.31: *Answers provided to question 3.2.1 and 3.2.2 in the Grade 12 August 2019 examination at The Schools.*

The answer to question 3.2.2 shown in Figure 4.31 above also illustrates another common error, which was to perform calculations as though the object was in equilibrium. Here students are applying a problem-solving approach that is inappropriate in this context. This may be because they looked only at surface characteristics of the problem (Section 2.5.12), without reading the context carefully. This was possibly encouraged by the emphasis on objects in equilibrium in the revision resource. One or two students drew free-body diagrams as though the mass was on an incline (with the normal force at an angle) and Figure 4.32 shows a student's excellent free-body diagram, which they were unable to resolve into relevant components or interpret in the abstract domain, suggesting that they are unable to translate between representations (Greeno, 1989).

A few answers indicated a persisting problem with the mathematical domain as well, with students again being unable to translate between representations (Greeno, 1989). Despite the student working through the resource in full, their answer shown in Figure 4.32 shows their inability to construct a mathematical statement of Newton's second law by using only forces or components of forces in one plane. This was a common error.

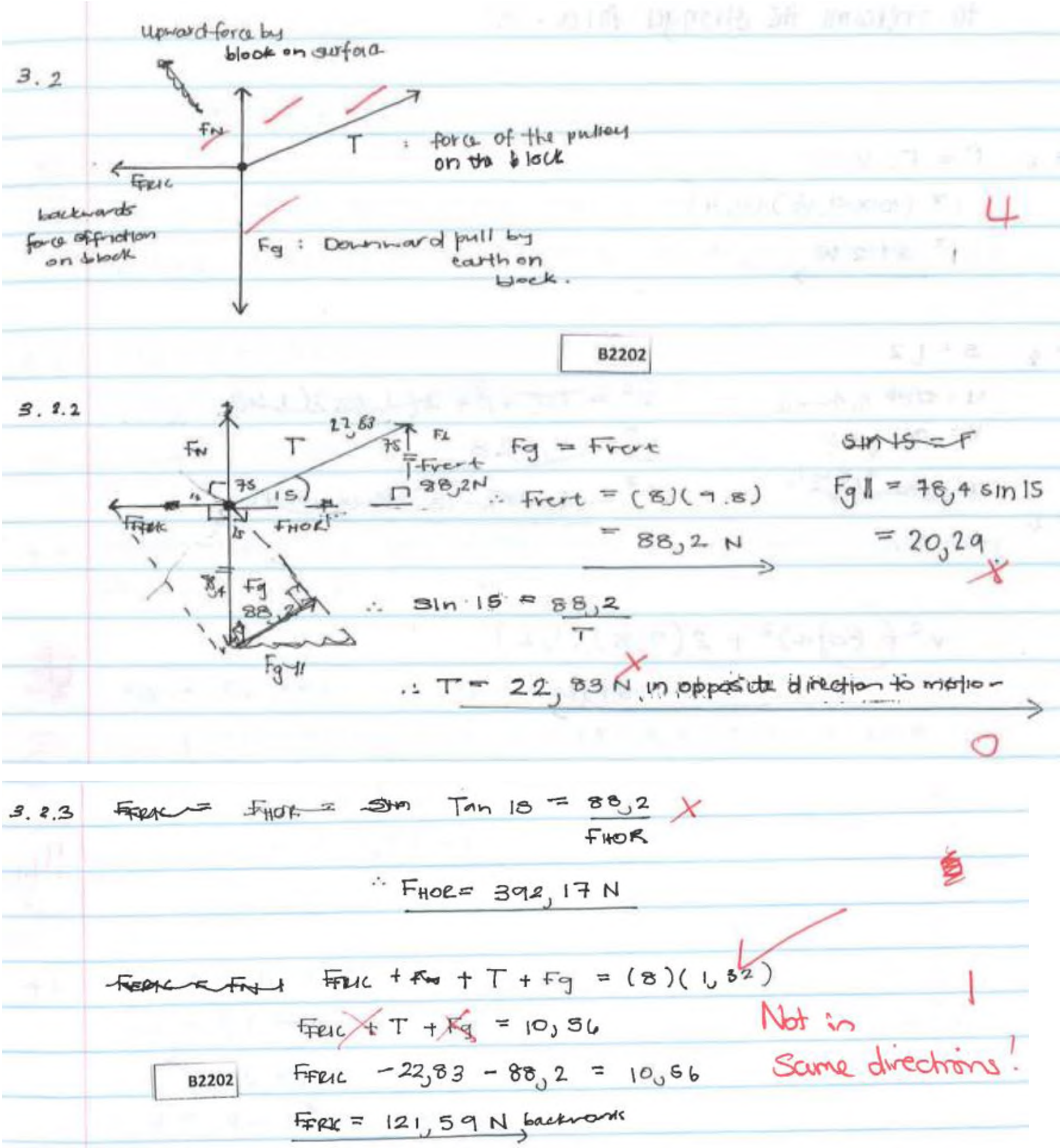
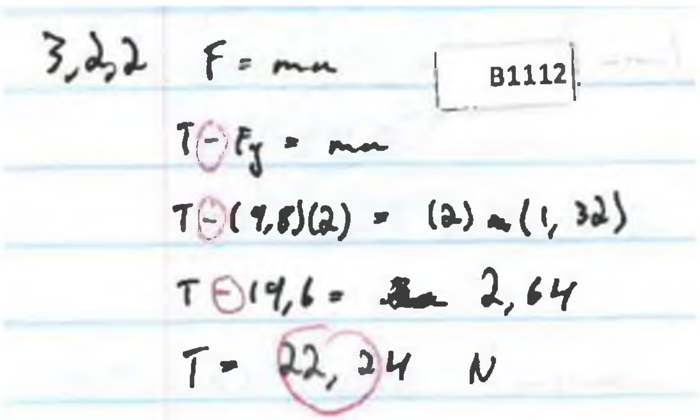


Figure 4.32: *Answers provided to question 3.2.1, 3.2.2 and 3.2.3 in the Grade 12 August 2019 examination at The Schools.*

The example in Figure 4.33 below shows that a student has not found the vector sum of the forces acting on an object, but has perhaps learnt a ‘formula’ from previous examples and applied this indiscriminately, which is a common approach among novices (Dhillon, 1998). Again, a think-aloud interview with this student would have provided insight into the student’s thinking. This student (B1112) indicated that he had not used the resource at all.


3,2,2 $F = ma$ B1112

$T - F_g = ma$

$T - (9,8)(2) = (2)(1,32)$

$T - 19,6 = 2,64$

$T = 22,24$ N

Figure 4.33: *Answer provided to question 3.2.2 in the Grade 12 August 2019 examination at The Schools.*

4.4.4 Iteration 4: Grade 11 Examination Revision, July 2019

The Grade 11 2019 group was given the opportunity to work through their resource in class, having recently written a test on Newton's second law and its application and shortly before the August examinations. 33% of the group indicated that they had completed the resource, 33% indicated that they had worked through most of the resource and 14% indicated that they had done part of the resource. There was a small group who did not respond, but there was no indication of who had not used the resource at all. Many students came to ask for help and worked through the resource in revision sessions with me, but simply did not complete the evaluation form or post-test.

This version of the resource included the section on equilibrium which was written for Iteration 3. It appears to address the misconception tested in question 1. This remains, however, the most persistent misconception tested by these questions, with a notable number of students still giving the incorrect answer after the intervention (see Figure 4.34).

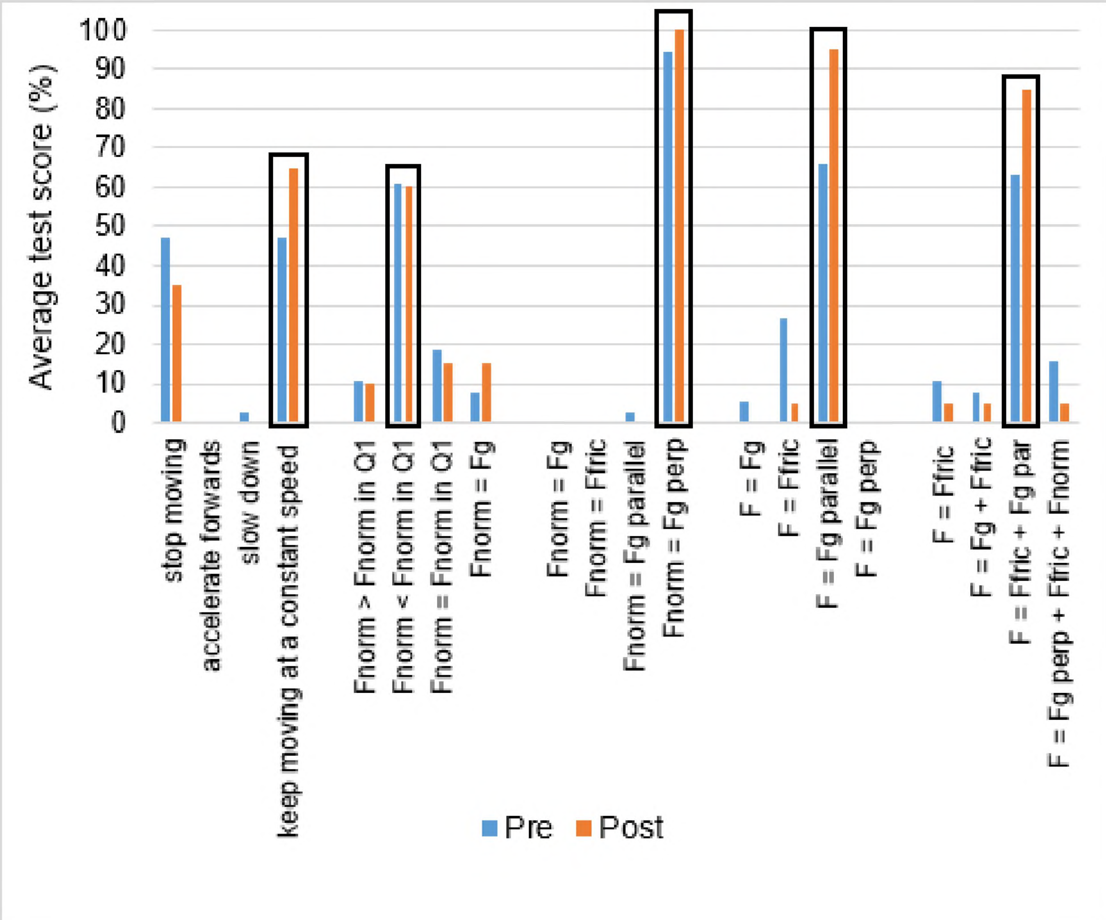


Figure 4.34: *Multiple choice responses for questions 1-5 in the pre-tests administered to the Grade 11 group at The Schools.*

The normalised gain for this iteration was 0.525, again suggesting a moderate gain (Hake, 1998), as students improved their score by half. The results of the pre-test (n = 37, M = 2.9, SD = 1.0) and the post-test (n = 20, M = 4.1, SD = 0.7) indicated through a t-test that there was a significant improvement in scores (p < .001).

The feedback provided by this group on the evaluation forms was extensive and generally positive. Many commented on

- the scaffolding (Collins, Brown and Newman, 1987) and
- the reduction of cognitive load that came with repetition (Sweller and Chandler, 1991) and

- self-diagnosis (Section 2.5.10):

"because it started off with easier questions and then progressed to the harder ones, it meant that I knew what I was doing from the start, and it was easy to point out where I was making mistakes" (student A2201)

and

"It talked me through each section and the examples got more difficult as they went on which made me so much more Comfortable dealing with these problems." (student A2219)

Students noted that the examples were progressively more difficult, which one student said

"confused me even more" (student A1202)

and another said

"challeng[ed] me" (student A2204).

Some saw the resource as a useful revision tool

"refreshes my mind" (student A3113),

"it explained something that I forgot or never knew" (student A1119)

and

"It was like a mini revision lesson" (student A2205).

The test written in early July (Appendix J), before the intervention, provided a useful comparison to the examination, written after the students had been exposed to the resource. Question 1.1 on the test and Question 1.4 in the examination were comparable. Some improvement is shown in the students' understanding of the concept by the reduction in the percentage of students choosing incorrect options, as shown in Figure 4.35 (the correct option in both questions was C).

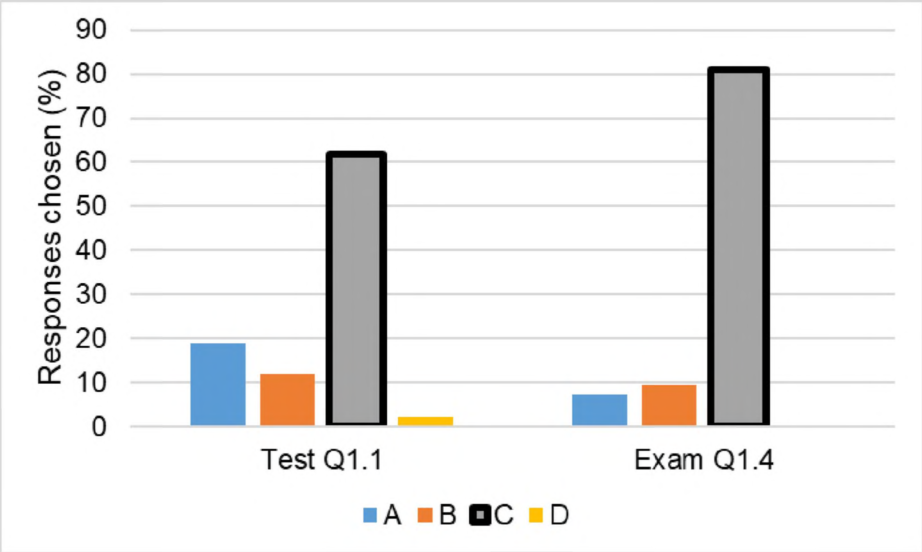


Figure 4.35: *The proportion of answers chosen for question 1.1 in the July Test and question 1.4 in the Grade 11 August 2019 examination (n = 41).*

Question 3 in the Grade 11 2019 examination (Appendix K) was similar to the exercises on the revision worksheet provided. This was the question with the lowest average in the examination, as is evident in Figure 4.36. Despite the intervention, this section remains a difficult topic for students, as described in Section 2.3. Question 4 in the examination was comparable to question 3 on the July test.

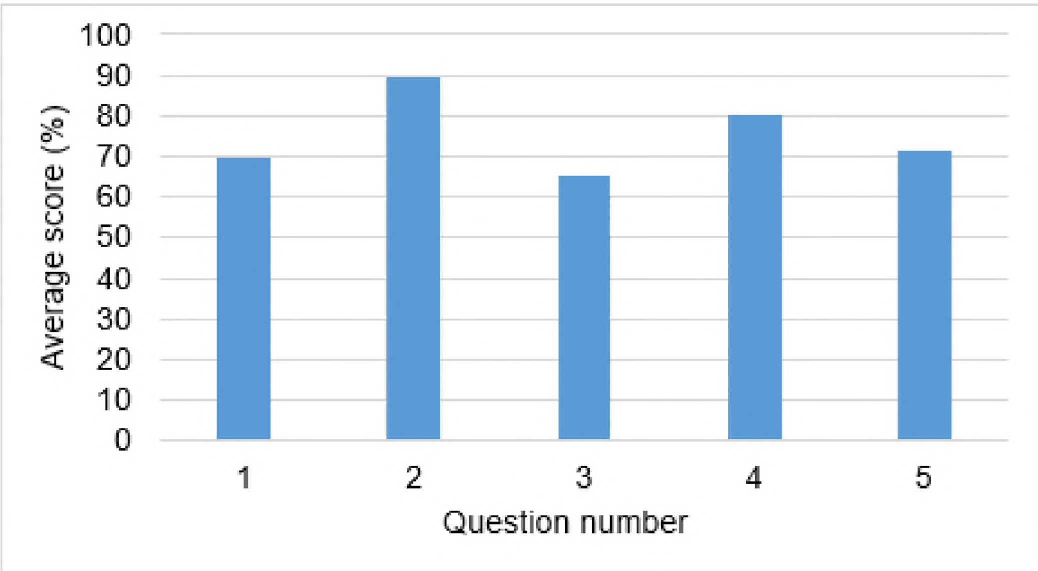


Figure 4.36: *Average score in each question in the Grade 11 August 2019 examination (n = 41).*

In the Grade 11 August 2019 examination, 29% of participants drew one or more additional diagram not stipulated in the question, for Question 3, while 57% drew one or more additional diagrams in Question 4. 81% of students drew in perpendicular components in Question 4, although they were not instructed to do so. The average score for drawing based on the rubric developed to analyse the quality of the drawing of free-body diagrams (Table 3.4) is shown in Figure 4.37. The average scores for those who completed the resource, who completed most of the resource and who completed part of the resource are shown in Figure 4.37. The free-body diagrams required in question 3.5 (object in equilibrium) and in question 4.1 (object on an incline) were assessed.

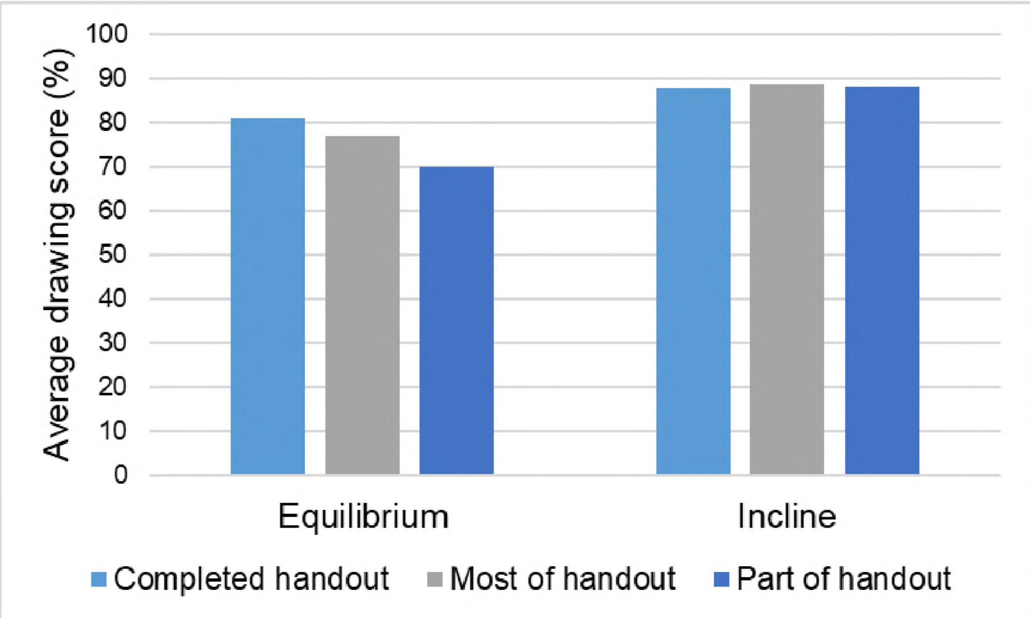


Figure 4.37: *A comparison of the average drawing score for students who completed the resource to varying degrees.*

Some answers were well presented, with free-body diagrams of high quality, such as shown in Figure 4.38.

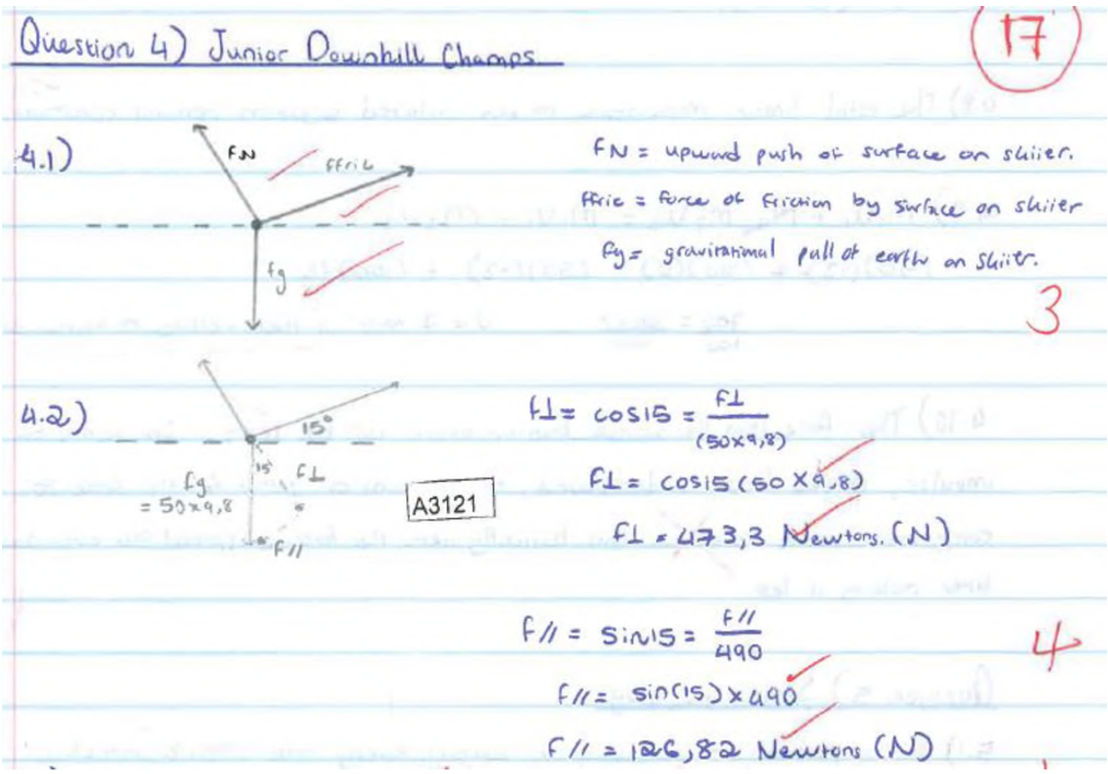
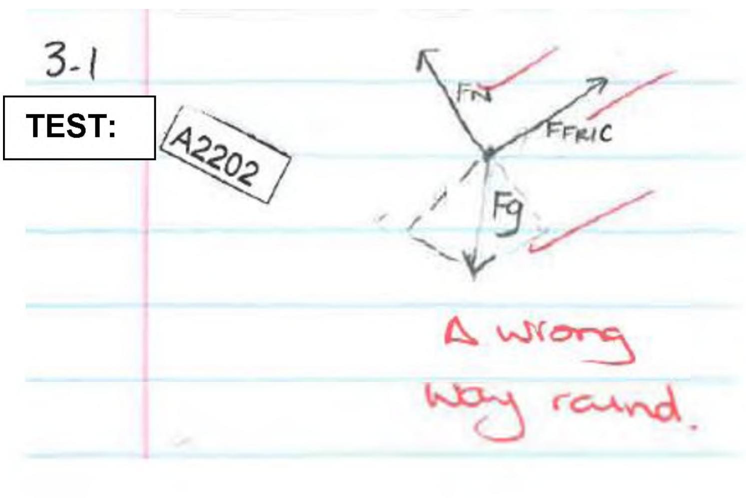


Figure 4.38: *An example of a good free-body diagram from the Grade 11 August 2019 examination, scoring 5/5 on the rubric (Table 3.4).*

Some students showed an improvement in their drawings (Figure 4.39) or their approach (Figure 4.40).



EXAM:

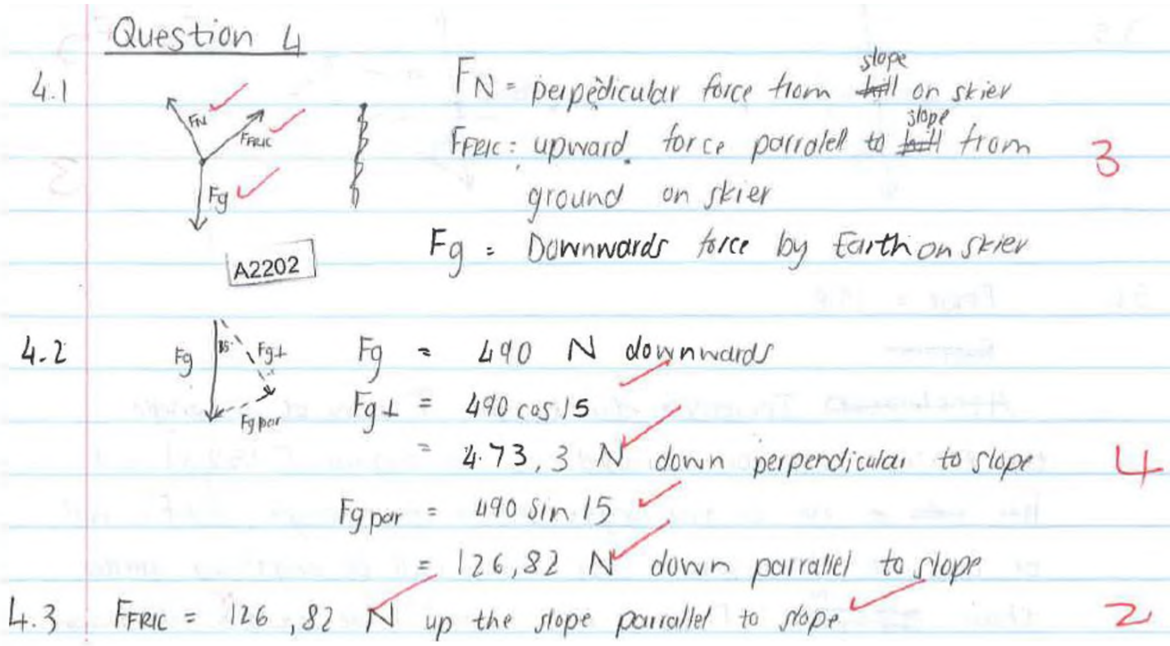


Figure 4.39: *An example of improvement in resolving the weight into its components from the Grade 11 test to the Grade 11 examination in August 2019.*

TEST: **EXAM:**

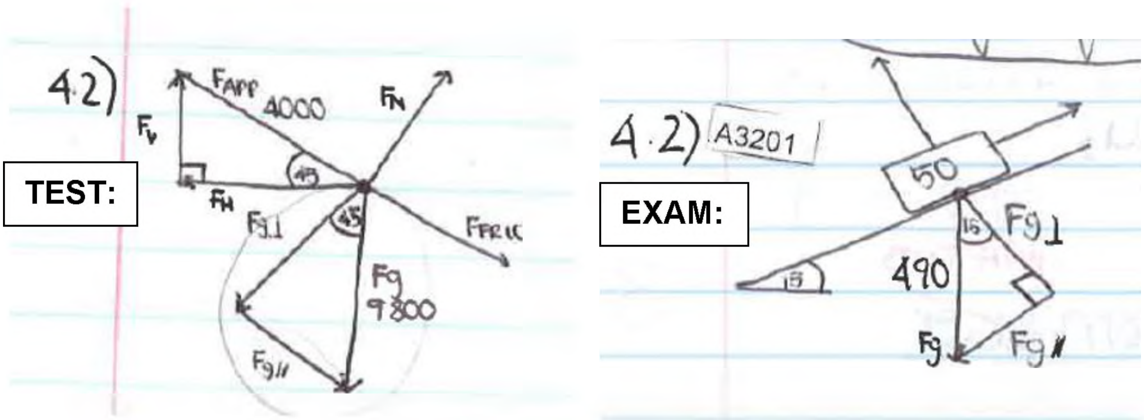


Figure 4.40: *An example of improvement in drawing from the Grade 11 test (left) to the Grade 11 examination (right) in August 2019.*

Few students were able to learn from the feedback and integrate their knowledge to use in the examination, as is evident from the student's answers in Figure 4.41, where they used an incorrect method twice in the test and comments were made by the marker. They repeated the incorrect method in the examination. This would be a case where some other form of intervention or an individual, personal intervention regarding this specific problem was perhaps necessary to bring about conceptual change (Posner et al., 1982).

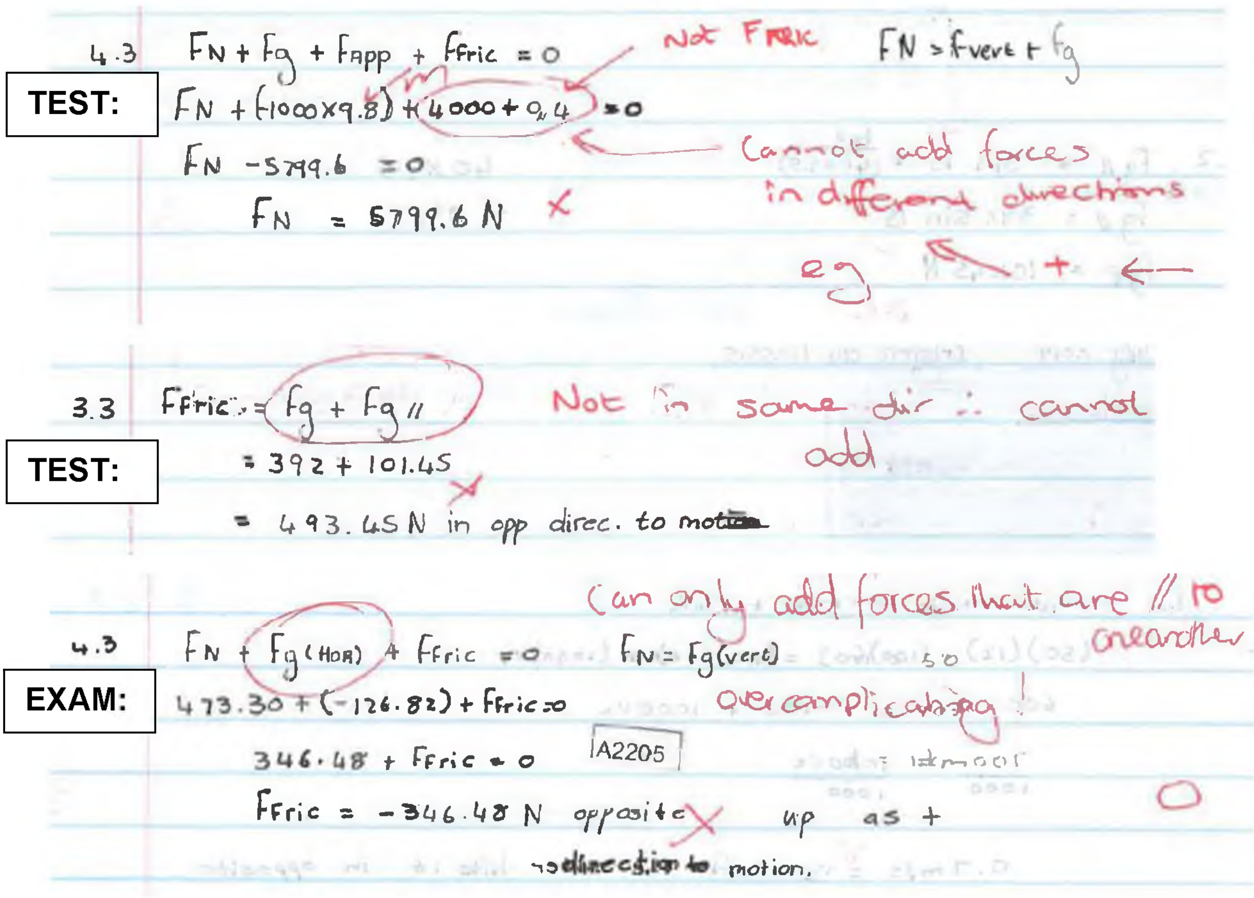


Figure 4.41: *A student's answers to three questions requiring the same approach in the Grade 11 July 2019 test and the Grade 11 August 2019 examination.*

Many of the errors seen in previous tests persisted in the examination, such as drawing the normal force the same length as the weight (Figure 4.42), confusing the orientation of an object (on a flat surface or an incline) (Figure 4.43 and Figure 4.44) and omitting forces or including forces that are not acting (Figure 4.45). This suggests that, while the resource helped some students, it did not eradicate the misconceptions for all students. As described in Section 2.1.5, misconceptions are resistant to change and often remain after teaching to correct them (Hung and Jonassen, 2006; Van Heuvelen, 1991a)

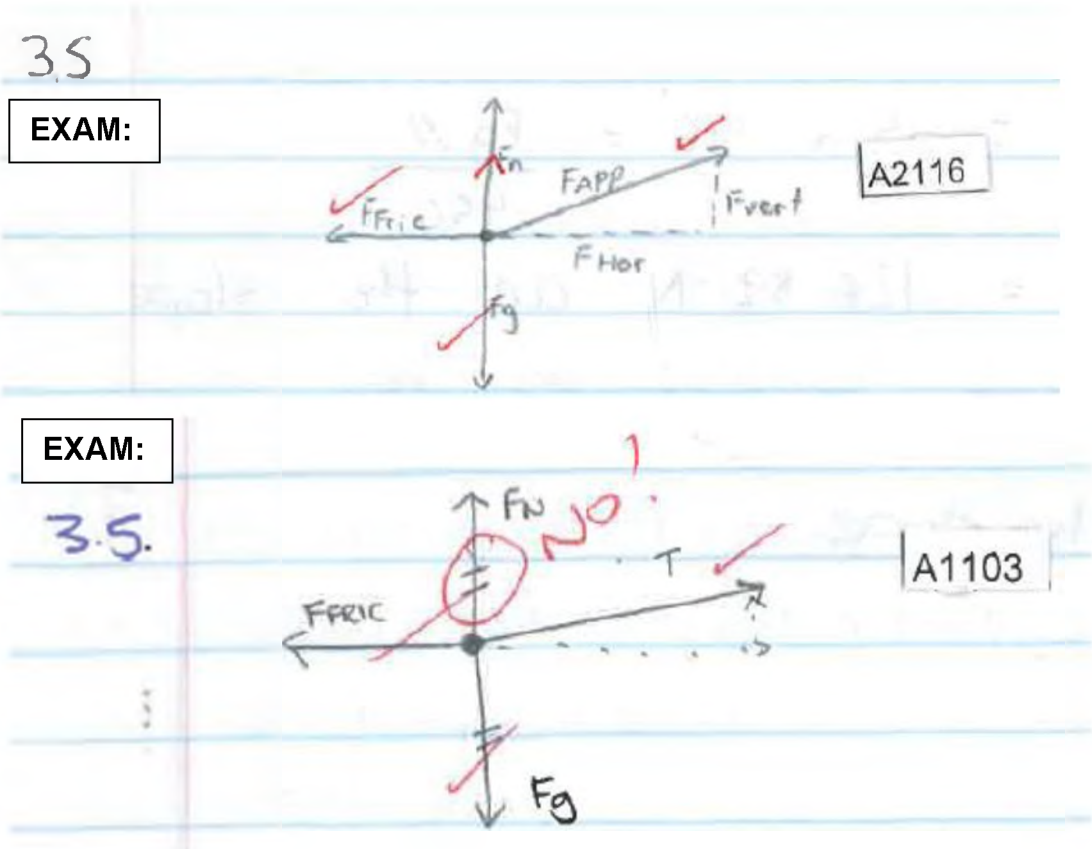


Figure 4.42: *Two answers to question 3.5 in the Grade 11 August 2019 examination.*

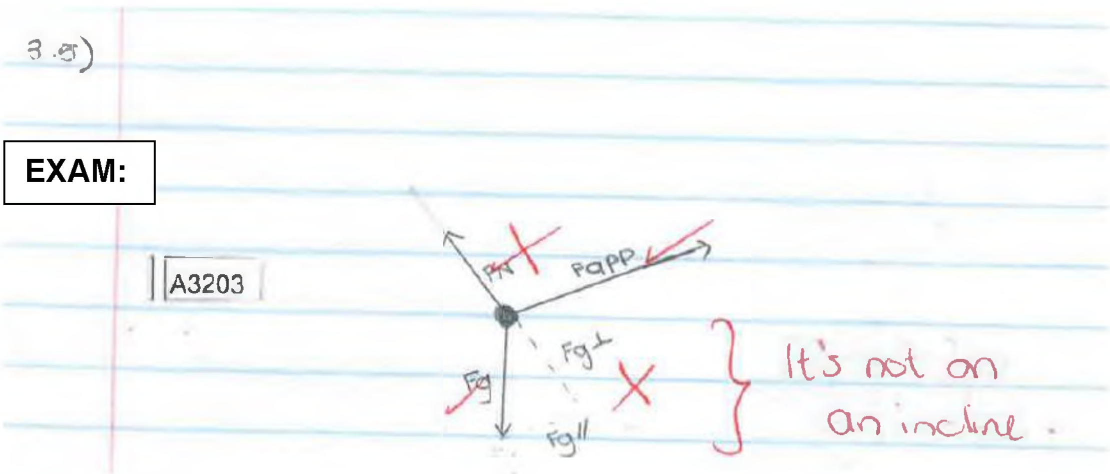


Figure 4.43: *An answer to question 3.5 in the Grade 11 August 2019 examination.*

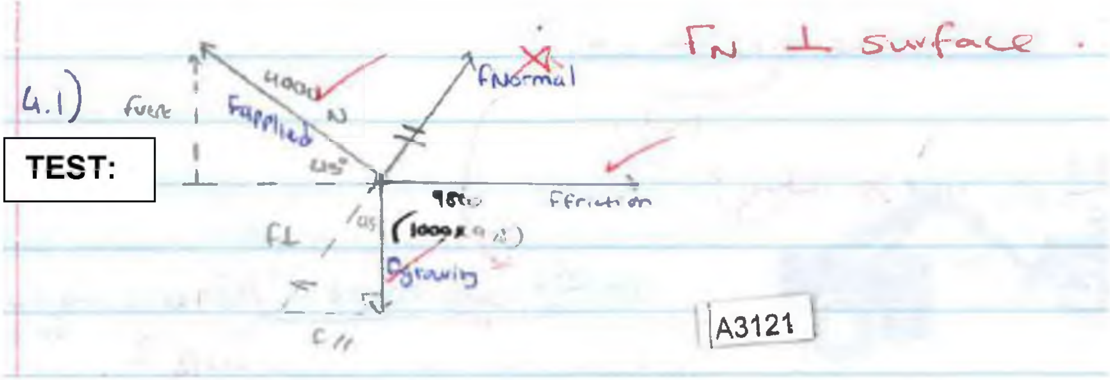


Figure 4.44: *An answer to question 4.1 in the Grade 11 July 2019 test.*

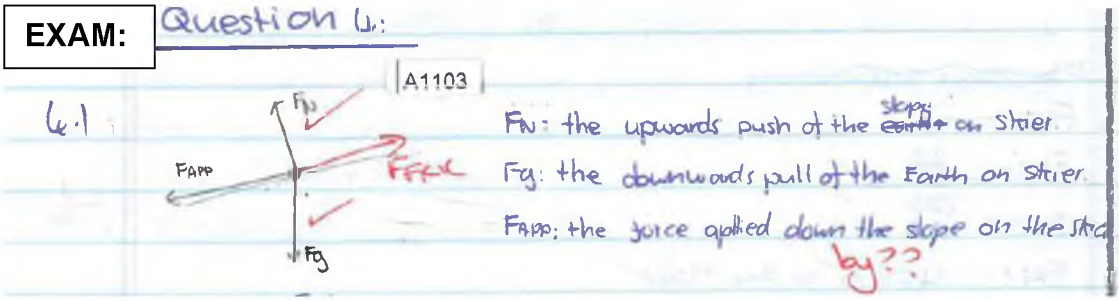


Figure 4.45: *An answer to question 4.1 in the Grade 11 August 2019 examination.*

Although no changes were made to the class notes on the topic of Newton's second law and its application from 2018 to 2019, it may be that, after all my consideration of this topic and my reading, I just taught the section better in 2019. The language used by students in their evaluation of the resource (using terms such as scaffolding) made me aware that I have made my approach more explicit as I have spoken to classes about my research and the value that I have seen in it. I have found myself emphasising the use of diagrams and being more deliberate in my explanations.

Although I did not teach a problem-solving method, I placed much greater emphasis on the importance and the value of drawing free-body diagrams in my 2019 Grade 11 course than in 2018. Students may also learn better if they understand the reason behind different pedagogical strategies (Van Heuvelen and Zou, 2001). In my lessons to the Grade 11 and 12 classes in 2019, I often spoke about what I had learnt through my reading and research to date and assured them that the advice I was giving (such as encouraging them to draw diagrams) was supported by studies and literature. In addition, I was able to reassure them that the mistakes that they were making were common and surmountable.

All improvements cannot be attributed to the resource alone, as it is difficult to isolate the factors that may have resulted in an improvement in students' understanding. Additional factors may include the learning and improvement in understanding that happens through normal teaching and through students' own self-study in preparation for examinations. It must also be acknowledged that more engaged students may benefit more from any revision materials.

CHAPTER 5

CONCLUSIONS

The application of Newton's second law was found to be one of the most challenging topics in the South African physics curriculum as it harbours misconceptions. Students also find that the concepts conflict with their experience and interpretation of the world around them.

A resource was developed through an iterative action-research process, informed by theories of learning, with four iterations. Drawing from the theory of cognitive apprenticeship (Collins, Brown and Newman, 1987) and cognitive load theory (Sweller, 1988), the resource modelled problem-solving and the use of multiple representations. It used scaffolded examples to assist students in developing their understanding of the concepts and acquiring schemas. There were sufficient similar examples to assist with schema acquisition. Students were then encouraged to 'explore' (theory of cognitive apprenticeship) their understanding in the worksheets, where they were exposed to more context-rich examples. By checking the revision worksheet solutions, students engaged in self-diagnosis (Section 2.5.10), which prompts them to evaluate their understanding and address conflict, as proposed by conceptual change theory (Posner et al., 1982). The resource contained worked examples and annotated diagrams to lower cognitive load, to model a problem-solving approach and to expose students to multiple representations.

The effectiveness of the resource was determined with pre- and post-tests. These tested the students' understanding of concepts that are frequently misunderstood, as well as qualitative evaluations. All four iterations showed a moderate gain from pre- to post-test ($0.46 < \langle g \rangle < 0.56$), with students showing a significant improvement ($p < .05$) in three of the iterations. The questions on Newton's second law and its application remained the most poorly answered questions, even after the intervention.

The student evaluations of the resources were positive, with students stating that the resource had improved their understanding of the concepts.

A qualitative evaluation of student drawing, using the rubric developed for this study, indicated an improvement in the quality of their drawings after the intervention.

I embarked on this research project in order to improve my practice and to deepen my understanding of physics teaching. My research has highlighted in my practice (habitual or customary action) what is good praxis (informed, committed action) and what needs to change (Zuber-Skerritt, 2016). My initial intention to provide useful resources has become a desire to present concepts in such a way as to help students to construct effective knowledge structures, and to engage with and interrogate their understanding (conceptual change theory) in order to achieve a more robust and accurate conceptual understanding.

5.1 Limitations of study

Marshman, DeVore and Singh (2018) conducted a study which looked at the extent of scaffolding and supervision on the effectiveness of working through a tutorial. They found that students who worked through the tutorial in a deliberate and engaged manner benefitted from it and were able to transfer their knowledge (Marshman, DeVore and Singh, 2018). My study relied on active and effective engagement with the resource by the students to be effective. Those who needed to improve their understanding and made good use of the resource benefitted from it. Iteration 2, when the resource was completed in class time, showed a marginally lower normalised gain than the other iterations. However, the resource could be refined or modified to be used more easily and independently by students, particularly if it is going to be used by students at other schools.

Lastly, Hung and Jonassen (2006) point out that a short intervention is not long enough to change problem-solving habits and each of the interventions in this study were conducted over a short period and, as such, were not able to change problem-solving habits. However, some improvement in one aspect of problem-solving strategy (drawing), showed improvement after the use of the resource, and this was a useful secondary gain of the intervention. The response to the post-tests and the return of evaluation forms was poor. With small samples, findings are easily influenced by outliers and this was evident in Iteration 3, as explained in the discussion of the results presented in Figure 4.29. The study was conducted over two years to allow more action research cycles.

The resource focussed on quantitative aspects of the application of Newton's second law, without emphasis on qualitative reasoning, although this may have developed through students' engagement with the quantitative examples. A useful addition to the resource could be more qualitative examples, which could be annotated to help students develop their conceptual understanding.

Although I piloted a resource with an evaluation form, I did not pilot the entire resource before Iteration 1. The resource and the questionnaire seemed to work for the students at The Schools, but having students work through them, thinking out loud would be useful to rule out ambiguity and inaccessible language. A think-aloud protocol is useful when developing a tutorial or resource (Singh, 2008c), so that you can hear what students are thinking and how they are interpreting instructions and activities. Marshman, DeVore and Singh (2018) have shown that those who work through a resource in a controlled setting stand to benefit from the process because they make use of the resource. They do, however, caution that ensuring that students engage effectively with a resource is a major challenge in education research (Marshman, DeVore and Singh, 2018).

It was difficult to assess the value of the intervention without knowing the extent of the students' engagement with the resource. A more controlled evaluation process such as completing the post-test and evaluation form in class would have helped to provide this information, although this would still be reported subjectively by the students. The timing of the interventions in the academic year meant that this part of the evaluation process could not happen in class. It would also have been useful to have had some students work through the resource in a controlled environment or with think-aloud assessments of the intervention to gauge its impact. Although many students worked through the resource in class in Iteration 2 and Iteration 4, they asked for help only when they needed it, rather than completing the entire resource under my scrutiny.

When I studied the students' examination scripts, I did not consider what was drawn on their question papers, as I only looked at their answer scripts.

5.2 Implications for the field

Study groups would be effective as there has been benefit shown for peer interaction even with minimum input from instructor (Mason and Singh, 2016b).

The summary of successful approaches in the literature review of this study may be of value to other science teachers who may be able to draw from the successful methods mentioned, so benefiting a wider community of practice. This study will also add to the research on learning physics in South African high schools.

5.3 Suggestions for further study

This intervention was tailored for The Schools and the prior knowledge expected and desired outcomes there. As an action-research intervention, the resource was tested and refined in this context. A useful extension of this study would be to test the resource more broadly at other schools with greater diversity of prior knowledge and language. The SELF evaluation (Section 2.5.13) could be used to make sure that the intervention is relevant.

It would also be beneficial to include a difficulty index, such as that used by McColgan et al. (2017), to ensure that the examples and assessments are comparable.

"*Education is not the learning of facts, but the training of the mind to think.*"

- Albert Einstein (1879 – 1955)

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APPENDIX

APPENDIX A.1: Approval of Ethics Application by RUESC

RHODES UNIVERSITY
Where leaders learn

Rhodes University Ethical Standards Committee
PO Box 94, Grahamstown, 6140, South Africa
t: +27 (0) 46 603 8055
f: +27 (0) 46 603 8822
e: ethics-committee@ru.ac.za

www.ru.ac.za/research/research/ethics

11 July 2018

Kate Cobbing
k.cobbing@[redacted]

Dear Kate Cobbing,

Re: HUMAN SUBJECTS ETHICS APPLICATION
A study of poorly understood physics concepts in the South African Physical Sciences curriculum to develop a targeted action-research intervention.
Reference number: 10297446
Submitted: 5/4/2018

This letter confirms that the above research proposal has been reviewed by the Rhodes University Ethical Standards Committee (RUESC) – Human Ethics (HE) sub-committee.

The committee decision is Approved.

Ethics approval is valid until 31 December 2018. An annual progress report is required in order to renew approval for the following year.

Please ensure that the ethical standards committee is notified should any substantive change(s) be made, for whatever reason, during the research process. This includes changes in investigators. Please also ensure that a brief report is submitted to the ethics committee on completion of the research. The purpose of this report is to indicate whether the research was conducted successfully, if any aspects could not be completed, or if any problems arose that the ethical standards committee should be aware of. If a thesis or dissertation arising from this research is submitted to the library's electronic theses and dissertations (ETD) repository, please notify the committee of the date of submission and/or any reference or cataloguing number allocated.

Sincerely,

JDames

Prof Jo Dames
Chair: Human Ethics sub-committee, RUESC- HE

APPENDIX A.2: Application for Ethical Approval by RUESC

SECTION A: GENERAL INFORMATION

Questions in this section of the application are intended to obtain information about the duration and level of research being proposed as well as the status and institutional affiliation of the principal/lead researcher and the co-investigators. Answers to questions marked with an asterisk are required and it will not be possible to submit your application form without providing this information.

Have you obtained a recommendation for ethical clearance from your departmental/faculty subcommittee? If yes, please upload relevant clearance documents here. If no, please obtain this clearance before continuing with this form. *

1. Title of research project *

A study of poorly understood physics concepts in the South African Physical Sciences curriculum to develop a targeted action-research intervention.

This title should be consistent with the title provided elsewhere (e.g. in a funding application, on the research proposal submitted to a faculty higher degrees committee etc.)

2. What are the anticipated start and end dates of the research project? *

May 2018 – May 2021

Ethics clearance is awarded for a stipulated period of time in order to cover the periods of data collection, data analysis and publication. The RUESC awards approval for a maximum period of three years. Applications for extensions of clearance after three years can be obtained by making a new application and uploading previous clearance documentation.

3. How will the research be funded? *

- ○ Self funded
- ○ Publically funded
- ◉ Privately funded

Self-funded refers to a researcher's own resources (e.g. the money in your personal bank account, although financial support from a charitable relative or family friend will also be considered as 'self-funded' research).

Publically funded refers to research funding that is awarded by the state (e.g. the National Research Foundation) and non-profit organizations (e.g.

CANSA). This is research that is paid for by funds raised through taxation or donation.

Privately funded refers to research that is funded through corporate sponsorship. In some instances, privately funded research can raise questions regarding conflicts of interest. When an applicant selects this option, the committee will be interested to know whether a conflict of interest exists (see Question 21 in Section D). Failure to disclose conflicts of interests would constitute a serious omission and may invalidate ethics approval.

4. Does the proposed research involve collaboration with external (to Rhodes University) research partner(s)? *

- ◉ No
- ○ Yes

'External' refers to individuals who are not employed by Rhodes University and who are not registered students at Rhodes University. An external partner may be affiliated to Rhodes University but, where another institutional affiliation exists, Rhodes University is not their primary institutional affiliation.

'Research partner' refers to co-researchers. In some instances, researchers may refer to research participants as research partners. For the purposes of this application, research partner is a term that indicates significant involvement in data collection and data analysis as well as the write-up and public dissemination of the research. For the purposes of this application, research participants who are not responsible for these processes should not be considered research partners. While this assumption may be problematic for those undertaking participatory research, the purpose of this question is to identify individuals involved in the project who have lines of reporting outside of Rhodes University. This information has various uses depending on the nature of the study. There may, for example, be legal implications with regards to third parties.

5. Indicate the level of the research project: *

- ○ Staff research project
- ◉ Student research project

Staff research is research that doesn't involve students as co-investigators and isn't being done for degree purposes. Student research is research undertaken for degree purposes (in partial or complete fulfillment of the requirements of the degree) and involves students as co/investigators.

5.1 Student researcher name and student number *
Kate Cobbing g00b0010

If more than one student is involved in the project then the names and student numbers of each student involved in the project must be listed here. If there is insufficient room, additional student details can be provided in an appended document which can be uploaded in Section H: Additional Documentation

6. Principal researcher's name, department/faculty and contact details *
Mrs Joyce Sewry ; Chemistry Department (Science Faculty); j.sewry@ru.ac.za

The principal researcher is normally the Rhodes University staff member making this application. However, in the case of student research (i.e. research that is undertaken for degree purposes), the supervisor's details must be provided in this field. In the case of collaborative research, the principal researcher should be the Rhodes University staff member making this application

7. Institutional affiliation of the principal researcher *

- (•) Rhodes University
- ( ) Other

SECTION B: RESEARCH METHODOLOGY

The questions in this section are designed to obtain information about which sources of information will be consulted, how these sources will be identified and accessed and the proposed methods of data collection. If you feel that there is insufficient space to provide adequate information to specific questions then you are advised to upload a copy of your research proposal/funding application in Section H: Additional Documentation. If you exercise this option then please ensure that the information contained in the attached documentation does not contradict any of the information provided in this application. Answers to questions marked with an asterisk are required and it will not be possible to submit your application form without providing this information.

8. What is the purpose of the research? *

I hope to verify with quantitative data which physics concepts South African high school students do not understand. I will study why these concepts present problems and what techniques and approaches have been successful in improving students' understanding of these concepts. With the findings of my study in mind, I will then develop a set of resources or an intervention to help students improve their understanding of these concepts.

My intention is to produce a resource that could be used independently by students who do not understand a concept the first time and wish to revisit it, or who would gain confidence from revisiting topics. This could also be a resource for students who have missed work through absence from school or for students in schools without science teachers.

This must be answered in a few sentences at most. In this section you need to say something about what you aim to achieve by doing this research and why it is important to do it. It is important for reviewers to understand the potential value of your research because it is against this that the possible risks of doing the research will be assessed.

Limit: 500 words

9. Provide a brief descriptor of each method of data collection and required sample *

Stage 1: Analyse the Itemised Data Capture (IDC) reports from Department of Basic Education and Independent Examinations Board (IEB) examinations to establish trends in students' understanding of concepts Nationally since the implementation of our current syllabus in 2008.

Stage 2: Analyse the examiners' reports (DBE and IEB) from 2008 - present, where problem areas and concepts are discussed and generalisations are made.

Stage 3: Analyse historically collected summaries of student responses and mark breakdowns per question for physics examinations written by Grade 10 – 12 students at [School A] and [School B] from 2012 – 2017.

Stage 4: Analyse the responses given in future routine physics tests and examinations by Grade 10 – 12 physics students at [School A] and [School B].

Stage 5: Interview selected students about their conceptual understanding of topics.

Stage 6: Develop a set of resources, based on my reading and findings - no data collection required.

Stage 7: Test the effectiveness of the resources by conducting a pre-test assessment of understanding, followed by a post-test after engagement with the set of resources.

Stage 8: Interview selected students about their responses to the set of resources and to the associated assessment of understanding.

Stage 9: Test the effectiveness of the resources for students at other schools.

The information that you provide in this section should be very brief. What is required is a quick overview of how the research will be conducted. You will be required to provide further details of methods of data collection and sampling in subsequent questions. In this section, please just list each method of data collection and a brief descriptor of the required sample for each method.

Some studies involve a single method of data collection (e.g. personal interviews) while others involve multiple methods of data collection (e.g. personal interviews, observations, a survey questionnaire). In this section you need to be very clear about each method of data collection that will be employed in your research.

You also need to be clear about your sources of information for each of these data collection activities (i.e. who will be interviewed and/or or who will be asked to complete your survey questionnaire).

If you are using multiple methods, then list and briefly describe each of them. For example: Stage 1 – Individual interviews with teachers; Stage 2 – Focus group discussion with students; Stage 3 – Make digital copy of curriculum documentation; Stage 4 – Observe classroom interactions.

Do not provide unnecessary detail.

Limit: 1500 words

10. Is gatekeeper permission required in order to access information and/or participants and/or research sites? *

- ○ No
- ◉ Yes

Gatekeepers vary, some examples are: State Department Officials, School Principals, Traditional Authorities, Hospital Superintendents, University Registrars, Directors of Human Resources, Business Owners, Landlords. If you need to negotiate access to participants or research sites then it is likely that you will require gatekeeper permission.

10.1 From whom will gatekeeper permission be sought? Indicate: (a) title and name, (b) institutional affiliation, (c) contact details *

The Headmaster; [School A + contact details]
The Headmistress; [School B + contact details]
District Office; Department of Basic Education; Eastern Cape
Heads of other local schools (not yet determined)
Please ensure that you provide this information for each gatekeeper from whom permission to conduct the research is required

10.2 Upload a template of the letter(s) requesting gatekeeper permission *

Request for consent from District Educational Department

Dear sir / madam

RE: Conducting research with Physical Sciences classes at a school in your district

I am conducting research through Rhodes University to verify which concepts in the high school physics curriculum are poorly understood. I will then put together a set of resources which is designed to promote a better understanding of these concepts. Lastly, I will test the effectiveness of these resources.

I would like to offer the Grade 10 – 12 learners at XXX school the opportunity to participate in a revision activity as they are preparing for examinations. They will be required to complete a short multiple choice assessment of understanding, then work through a set of resources before completing another short assessment to establish the effectiveness of the intervention. I may ask some of the willing participants some follow-up questions about how they best understand physics concepts.

I believe that participants will benefit from this process, as the intervention should improve their understanding of the concepts and it will be timed to coincide with their examination revision.

I would like to include these Physical Sciences classes in my study to increase the number of learners who use this intervention, to better test its effectiveness. However, I would need signed consent from all those learners who would like to participate, as well as their parents, obtained with the consent and help of the school. Please see the forms attached.

This study has been approved by the Rhodes University Ethical Standards Committee (RUESC) and my letter of ethical clearance is attached.

The school will not be mentioned by name and no names of participants will be included. All information collected will be treated confidentially and results will be anonymous. Only I will have access to the raw material and data containing names.

If you are happy for me to include the learners from XXX school in this study, please reply using the form below or whatever other means is acceptable and convenient for you.

Please may I also have your permission to share and publish the findings of my research. I will gladly share the findings of my research with you on completion of my study, should you be interested.

If you require any further information, please do not hesitate to contact me.

Thank you.
Mrs Kate Cobbing (email address)
Student number: G00B0010
Rhodes University

PLEASE TURN OVER THE PAGE FOR CONSENT DECLARATION

CONSENT FOR PARTICIPATION IN MRS COBBING'S RESEARCH PROJECT:

Please mark the applicable boxes (□):

I,..
(position: ....),
understand what I have read above and agree to

□ allow the Grade 10 – 12 Physical Sciences learners of XXX school to participate in a revision programme and allow Mrs Cobbing to use the responses that they give in the pre-intervention test and the post-intervention test as part of her data collection.

□ allow Grade 10 – 12 Physical Sciences learners at XXX school to be interviewed about their understanding of physics and will allow Mrs Cobbing to use their responses as part of her data collection.

□ give permission for the findings of this study to be shared and published.

SIGNED: .... DATE: ....

APPENDIX A.3: Request for consent from head of school

Letter to Principal of school approached

Dear sir / madam

RE: Conducting research at your school with your Physical Sciences classes

I am conducting research through Rhodes University to verify which concepts in the high school physics curriculum are poorly understood. I will then put together a set of resources which is designed to promote a better understanding of these concepts. Lastly, I will test the effectiveness of these resources.

I would like to offer the Grade 10 – 12 learners at your school the opportunity to participate in a revision activity as they are preparing for examinations. They will be required to complete a short multiple choice assessment of understanding, then work through a set of resources before completing another short assessment to establish the effectiveness of the intervention. I may ask some of the willing participants some follow-up questions about how they best understand physics concepts.

I believe that participants will benefit from this process, as the intervention should improve their understanding of the concepts and it will be timed to coincide with their examination revision.

I would like to include your Physical Sciences classes in my study to increase the number of learners who use this intervention, to better test its effectiveness. However, I would need signed consent from all those learners who would like to participate, as well as their parents. Please see the forms attached.

This study has been approved by the Rhodes University Ethical Standards Committee (RUESC) and my letter of ethical clearance is attached.
Your school will not be mentioned by name and no names of participants will be included. All information collected will be treated confidentially and results will be anonymous. Only I will have access to the raw material and data containing names.

If you and your Physical Sciences teacher(s) are happy for me to include your learners in this study, please return the declaration of consent below to me (by email, if convenient) and I can then deliver the consent forms and arrange a convenient date for the revision intervention, preferably in the lead up to a set of examinations.

In signing this, you also give me permission to share and publish the findings of my research. I will gladly share the findings of my research with you and with your Physical Sciences teacher(s) on completion of my study.
If you require any further information, please do not hesitate to contact me.

Thank you.

Mrs Kate Cobbing (email address supplied)
Student number: G00B0010
Rhodes University

PLEASE TURN OVER THE PAGE FOR CONSENT DECLARATION

CONSENT FOR PARTICIPATION IN MRS COBBING'S RESEARCH PROJECT:

Please mark the applicable boxes (□):

I,...(position: ....),

of ....(SCHOOL NAME) understand what

I have read above and agree to

□ allow the Grade 10 – 12 Physical Sciences learners at my school to participate in a revision programme and allow Mrs Cobbing to use the responses that they give in the pre-intervention test and the post-intervention test as part of her data collection.

□ allow Grade 10 – 12 Physical Sciences learners at my school to be interviewed about their understanding of physics and will allow Mrs Cobbing to use their responses as part of her data collection.

SIGNED: .... DATE: ....

Reviewers need to see these letters in order to establish that the information you intend to provide to gatekeepers regarding the research is complete and accurate. Please note that gatekeeper permission may not be sought before ethics clearance has been obtained.

Select up to 10 files to attach. You have attached 2 files (27.96 KB). You may add up to 8 more.

Reviewers need to see these letters in order to establish that the information you intend to provide to gatekeepers regarding the research is complete and accurate. Please note that gatekeeper permission may not be sought before ethics clearance has been obtained.

11. Which of the following activities does this research involve: *

- ☑ A: Interaction with human subjects
- ☐ B: Observation of public behaviour (I.e. complete observer)
- ☑ C: The collection of personal artefacts (E.g. photographs, diaries)
- ☐ D: Accessing personal records containing private and/or confidential information (E.g. patient records)
- ☑ E: Accessing information already published in the public domain (E.g. tweets; newspaper articles)
- ☐ F: Other

Select as many options as apply. If these options do not describe your methodology then please select "other".

11-A: Provide a comprehensive description of: (a) the nature of the interaction(s); (b) their frequency and duration; (c) the procedure(s) involved *

Answers below pertain to interactions specific to my research only. I will have extensive, regular interaction with most of my subjects, as I teach them.

INTERVIEWS:
(a) I will interview selected students. There will be two interviews: To discover how successful students build an understanding of concepts (A) and then to evaluate the impact of the resources that I develop (B). Interview A is intended to be semi-structured, with basic questions to guide the students' responses, but flexibility to prompt students to provide more detail on their construction of understanding. Interview B may take the form of a semi-structured interview or stimulated-recall interview, asking them

directly about their responses in the tests and their thought processes during the test.

(b) One interview (per student) of approximately 30 minutes to establish how they understand concepts. One interview (per student) to evaluate the set of resources after use (approximately 30 minutes).

(c) Interview, which is recorded digitally, transcribed (by me) and the transcript made available for the student to check.

EVALUATION OF RESOURCES:
(a) Answering questions on a topic (using an online platform or a printed sheet), engaging with resources on the topic (most likely digital resources) and then answering different questions on the same topic.

(b) Each student would complete the assessment cycle of pre-test, use of resources and post-test once for each topic. I anticipate the pre-test and post-test taking between 15 and 30 minutes each to complete and the students would have as long as they like to engage with the resources provided. I would like to run these tests more than once (e.g. July examination preparation and November examination preparation) to increase my sample size and may make changes to the assessments and resources, which would allow students to participate in both revision opportunities.

(c) Once I have verified the concepts that need intervention, I will create a set of resources designed to help students improve their understanding of one of these concepts and administer a pre-intervention test and a post-intervention test. These tests will be different, but will both use crafted multiple choice questions to assess conceptual understanding of the topic. The post-intervention test will include an evaluation of the intervention using Likert scale questions, multiple choice questions and some free response questions.

Most research falls into this category. It includes both direct and technologically mediated interactions as well as all types of observational research where access is restricted and must be negotiated (e.g. a school classroom or hospital ward).

Limit: 3000 words

11-A: Attach a draft copy of the proposed interview schedule and/or survey questionnaire and/or description of the assessment task and/or copy of the observation schedule etc. as applicable *

Sample / Draft Interview Questions

These interviews are intended to be semi-structured, with basic questions to guide the students' responses, but flexibility to prompt students to provide more detail on their construction of understanding.

Post-analysis

[Intended for students who show sound understanding of concepts or who answer questions successfully]

GRADE: ___ GENDER: _____ SCHOOL: ___________________

1. Do you find that you understand concepts when they are taught in class?
2. If yes, what helps you to understand them?
3. Can you explain how you make sense of the concepts?
4. If no,
   4.1 how do you build your understanding?
   4.2 What methods help you to improve your understanding?
   4.3 Do these methods vary between concepts?
5. Grade 11 and 12 learners only:
   5.1 How have you felt your understanding of concepts has developed from Grade 10?
   5.2 What do you think is the reason for this?

Post-intervention Test

[Intended for students whose results changed significantly with the intervention]

GRADE: ___ GENDER: ____ SCHOOL: ___________________

1. Which resources did you use?
2. How do you think the intervention changed your understanding of the topic?
3. Why do you think the intervention had an effect on your understanding?
4. Which resource did you find most helpful?
5. Why?
6. Did you find any of the resources confusing?
7. Which resources were confusing and why did you find them confusing?

Sample / Draft Pre-Test and Post-Test

I cannot analyse responses or documents until I have ethical clearance. I will choose a topic for intervention based on my findings, so this test is simply a sample to show the type of questions that I will ask.

I will most likely use an established, well-tested concept inventory available to verified physics teachers.

An example follows on the next page (I have used sample questions as the concept inventories have to be used under controlled conditions).

The evaluation below is an example of the kind of questions that would be administered after the post-test as a means to gather feedback on the students' experience and perceived value of the resource. Again, this will develop based on the type of resources that are used, but the questions will be similar to those below.

<u>EVALUATION OF RESOURCE</u>

GRADE: _________ GENDER: _____ SCHOOL: _____________

I accessed and engaged with the following resources:

□ video on circuits (Khan Academy)
□ video on circuits (Siyavula)
□ worked example on current
□ pHet Simulation and activity
□ Siyavula text book
□ Siyavula exercise

I found the resource package

very helpful	rather helpful	a little helpful	unhelpful	confusing
□	□	□	□	□

The time that I spent engaging with the resource was

worthwhile	fair	not worthwhile	unreasonable
□	□	□	□

If you found the process useful, what do you think was the most significant reason for your improvement in understanding?

□ I needed to hear the concept again

□ I needed to hear the concept explained in a different way

□ I spent more time on the work

Would you engage with resources on a different topic that you are struggling with?

Yes	No
□	□

While minor changes may be made to these documents before they are finalised, the committee requires this documentation to determine the constitutionality of the questions asked and to assess the sensitivity of the information obtained

Select up to 6 files to attach. You have attached 2 files (205.41 KB). You may add up to 4 more.

11-A: Indicate the Minimum/Maximum sample size required *

I expect to interview approximately 5 students per grade about their learning methods and construction of understanding (so 15 in total) and about 8 - 10 per grade in the post-test review, although this number will depend on the extent of participation.

I will offer the opportunity to participate in the revision of a topic using the targeted resources to all 270 Physical Sciences students who I have contact with. The number of participants will depend on how many take the opportunity and give consent for their responses to be included.

Likewise, the number of participants from other schools will depend on the response from schools and the number of students who are willing to participate in an evaluation of the effectiveness of the resources.

Sample size is indicated differently depending on the nature of the interaction. It usually refers to the number of participants but can also be

stated in terms of the number of documents (e.g. newspaper articles, personal records etc.).
If your research involves different stages of data collection and samples vary in relation to these different stages then indicate expected minimum and maximum sample sizes for each of the stages.

Limit: 1000 words

11-C: Provide a comprehensive description of the nature of the personal artefact(s) to be collected. A statement clarifying whether or not these artefacts will be returned (and when) is also required. *

I wish to use test and examination responses that highlight poorly understood concepts.

Original tests and examinations will be returned to students, with parts that I wish to use in my research captured anonymously before they are returned and stored securely (as detailed below under data storage section). Grade 12 assessments are not returned, but are all kept to be included in a final School Based Assessment Portfolio and so are filed in portfolio files in their teachers' classrooms. This is our normal procedure and has proved to be secure.

In addition to the collection of responses in future, I hope to use data that I have collected to inform my teaching since 2012. This has been securely stored and, as I am looking at trends rather than individual responses, is anonymous. This will add a depth to this study, as it will allow me to look at conceptual understanding over a longer period of time at our institutions, alongside the National data that I will be analysing. Please see two letters in support of the use of this historically collected, anonymous data in Section H, as well as two samples of the information that I hope to use.

Examples of personal artefacts include drawings, personal diaries, photographs, personal correspondence etc.

Limit: 2000 words

11-C: Will the artefacts be duplicated? *

- (•) Yes
- ( ) No

In other words, will the artefact be photocopied or will a digital (or some other type) of copy be made of the original artefact?

11-C: Indicate the Minimum/Maximum sample size required *

There is no requirement here, but the number of responses collected will depend on the number of interesting and note-worthy responses that are given and also on the variety of responses given.

Sample size is indicated differently depending on the nature of the artefacts to be collected. It may also be appropriate to indicate that sample size is 'Not Applicable'.

Limit: 1000 words

11-E: Provide a comprehensive description of the precise nature of the information that will be accessed *

Department of Basic Education (DBE) Diagnostic Reports, available to all (https://www.education.gov.za/Resources/Reports.aspx)

Independent Examinations Board (IEB) Examiners' Reports and Itemised Data Capture reports. While these are available for download from the IEB website for all IEB teachers and so are in the public domain, I cannot provide the link, as only IEB teachers have access. I have attached correspondence verifying that this information is considered to be in the public domain in Section H.

Please ensure that you provide enough information for the committee to properly assess the sensitivity of the information to be accessed and the sorts of risks that are likely to arise from accessing this information for research purposes.

Limit: 2000 words

12. Will any records contain any individually identifying information? This is includes information about third parties *

- ○ No
- ◉ Yes

12.1. Will anonymity and confidentiality be preserved with respect to data? *

- ○ No
- ◉ Yes

Explain how this will be achieved *

The examination and test scripts that I will be using as a resource will be identifiable and my mark sheets will have student names and their marks, as I will be using our usual school assessment process to gather some of my data.

However, for the purposes of this research, the responses to test and examination questions that I select to use will be copied without the student's name and so will be stored for use anonymously. As soon as the marking and moderation process for examinations is complete, I will save a copy of the spreadsheet of results and responses in my personal folder with individual names removed and will use this for my data analysis. I will leave the gender of the individuals in this spreadsheet in case I want to study the effect of this variable at a later date.

I will code the student responses and interviews for anonymity (e.g. Student A, Student B, Interviewee A, Interviewee B, etc). Schools will also be coded to prevent identification (School X, School Y) and I will not refer to the names of [School A] and [School B] in the write-up.

Please ensure that you are familiar with best practice guidelines and refer to these guidelines where necessary

Limit: 3000 words

13. Does the proposed study constitute health research? *

- ◉ No
- ○ Yes

Health Research is broadly defined in the Health Act and the Department of Health 'Ethics in health research' guidelines as including but not limited to "research that contributes to knowledge of: the biological, clinical, psychological, social welfare matters, or social processes as regards humans; the causes and effects of and responses to disease effects of the environment on humans; methods to improve health care service delivery new pharmaceuticals, medicines, interventions and devices new technologies to improve health and health care".

14. Will the research involve the use of anything (e.g. a procedure/ technology/therapy etc.) which constitutes Intellectual Property (IP) and for which particular protections or permissions apply? *

- ◉ No
- ○ Yes

There are various forms of Intellectual Property. In psychology, for example, measurement instruments used to evaluate mood and measure cognitive ability are generally copyright protected and cannot be used without obtaining prior permission.

15. Does any aspect of the research require the involvement of an appropriately trained and/or accredited and/or registered professional? *

- ◉ No
- ○ Yes

For example, the South Africa law requires that only appropriately trained and accredited healthcare workers (e.g. medical doctors, pharmacists, psychologists) who are registered with the Health Professions Council are authorized to perform certain healthcare procedures. Similar requirements exist with regard to research involving animal subjects (i.e. that certain procedures can only be performed by a veterinarian or wildlife biologist).

16. List and briefly describe all of the sampling criteria *

I will analyse the Itemised Data Capture (IDC) reports from the Department of Basic Education (DBE) and the Independent Examinations Board (IEB) to establish which broad physics topics are not well understood amongst Grade 12 students across South Africa. I will use the Examiners' Reports and IDC reports from 2008 - 2018, which will allow me to evaluate conceptual problem areas from the implementation of the syllabus that we currently follow.

My main research site will be the schools at which I teach - [School A] and [School B] in [my town]. My study will include boys and girls in Grade 10 – 12 (aged 16 – 18) from these schools and from any schools that I may approach later in my study.

All the Grade 10 – 12 students (approximately 270 students) at [School A] and [School B] will write the tests and examinations for routine school assessment purposes, but I will only use the responses of those students who have (along with their parents) returned consent forms. I will analyse these responses to identify poorly understood concepts across the grades at these schools.

I will conduct interviews to better understand how students build their understanding of concepts to guide my development of a successful intervention. I intend to choose students for these interviews who show an understanding of concepts, but again will choose only those who show a willingness to participate in the research and give their consent.

Those students who wish to participate will have access to the set of resources designed to help students improve their understanding of one of these concepts. They will be asked to complete a pre-intervention test and a post-intervention test. I will use information only from those who have given their consent.

Having received the responses to post-intervention tests, I will interview some students about their responses, understanding and experience of the intervention. I will choose to interview students whose pre-test and post-test scores varied significantly.

Should the resource be successful, I hope to test the effectiveness of the intervention in other environments. I would invite [local] schools and possibly also other schools from further afield where I know the Physical Sciences teacher to participate. The number of schools and the level of engagement with students (tests and intervention only or interviews as well) will be determined by the response from schools.

This must be a complete and accurate account of each criterion upon which an inclusion/exclusion decision is based. E.g. Age; gender; race; ethnicity; geographic location; institutional affiliation; socio-economic status; health status; publication date; keywords; type of social media platform etc.

Limit: 2000 words

16.1 Is any information collected from sources located in an institutional setting? (e.g. hospital, prison, school, university)? *

- ○ No
- ◉ Yes

If yes, then you will be required to obtain gatekeeper permission. Please check your answer to Question 10

16.1.1 Identify the institutions(s), including: (a) Name, (b) Location, (c) Type of institution *

[School A]; [town]; school
[School B]; [town]; school
Other local schools (to be determined)

Limit: 1000 words

17. Does any aspect of this research require obtaining informed consent and/or assent? *

- ○ No
- ◉ Yes

If subjects do not have the requisite decisional capacity (because they are too young, too ill, or intellectually impaired, or have a psychological disorder such as dementia) then informed consent must be obtained from a legal guardian. However, the assent of such persons should also be obtained if at all possible.

17.1 Upload templates of all information letter(s) and consent and assent form(s) *

APPENDIX A.4: Letter to Parents requesting consent for participation

Dear parents

I am conducting research through Rhodes University to verify which concepts in the high school physics curriculum are poorly understood. I will then put together an intervention (videos / worksheets / tutorials) which is designed to promote a better understanding of these concepts. Lastly, I will test the effectiveness of this intervention.

To do this, I would like to use the responses to questions in tests and examinations that your son / daughter supplies over their remaining time at school. Their participation in the research and their responses in research-related forms and tests will in no way affect their school results. All their responses will be kept completely anonymous in my research.

Your son / daughter will also need to give their consent to participate and may ask me to withdraw them from the sample group at any stage.

In addition, Grade 10 – 12 students will have the opportunity to participate in a revision activity as they are preparing for examinations. They will be required to complete a short multiple choice assessment of understanding, then work through a task or set of resources (the intervention) before completing another short assessment to establish the effectiveness of the intervention.

I believe that participants will benefit from this process as the intervention should improve their understanding of the concepts and it will be timed to coincide with their examination revision.

Again, your son / daughter will give consent to participate and may ask me to withdraw them from the sample group at any stage. All their responses will be completely anonymous.

I would like to interview some students about how they build an understanding of concepts. This will require them to consider how they understand concepts and what approaches work best for them, which I believe will help them focus on their learning methods. Their insights and methods may help others through this study. You may ask for a copy of the proposed interview questions, should you wish.

If you are happy for your son / daughter to assist me in my research and/or participate in the revision programme and / or participate in an interview, please complete the relevant consent declarations over the page and return them to me by email.

This study has been approved by the Rhodes University Ethical Standards Committee (RUESC) and my letter of ethical clearance is attached.

In signing this, you also give me permission to share and publish the findings of my research.

Thank you.
Mrs Cobbing (email address supplied)

PLEASE TURN OVER THE PAGE FOR CONSENT DECLARATION

CONSENT FOR PARTICIPATION IN MRS COBBING'S RESEARCH PROJECT:

Please mark the applicable boxes (□):

I, ..., understand what I have read

above and as the parent of ....

(please type the name and surname of your son / daughter)

□ will allow Mrs Cobbing to use the responses that my son / daughter gives in tests and examinations for the rest of their time at school, as part of her data collection, as outlined above.

□ agree to allow my son / daughter to participate in a revision programme and allow Mrs Cobbing to use the responses that they give in the pre-intervention test and the post-intervention test as part of her data collection.

□ will allow my son / daughter to be interviewed about their understanding of physics and will allow Mrs Cobbing to use their responses as part of her data collection.

SIGNED: .... DATE: ....

APPENDIX A.5: Letter to students requesting consent for participation

Dear Physics student

I am conducting research through Rhodes University to verify which concepts in the high school physics curriculum are poorly understood. I will then put together an intervention (videos / worksheets / tutorials) which is designed to promote a better understanding of these concepts. Lastly, I will test the effectiveness of this intervention.

To do this, I would like to use your responses to questions in tests and examinations over your remaining time at school. Your responses to this form and other research-related forms and tests will in no way affect your school results. All your test and examination responses will be kept completely anonymous in my research.

You may ask me to withdraw you from the sample group at any stage.

In addition, you will have the opportunity to participate in a revision activity as you are preparing for examinations. This will require you to complete a short multiple choice assessment of understanding, then work through a task or set of resources (the intervention) before completing another short assessment to establish the effectiveness of the intervention.

I believe that you will benefit from this process as the intervention should improve your understanding of the concepts and it will be timed to coincide with your examination revision.

Again, you may ask me to withdraw you from the sample group at any stage and all responses will be completely anonymous.

I would like to interview some students about how they build an understanding of concepts. This could help you to consider how you understand concepts and what approaches work best for you. Your insights and methods may help others through this study.

If you are happy to assist me in my research and/or participate in the revision programme and / or be interviewed, please complete the relevant consent declarations below and return them to me.

This study has been approved by the Rhodes University Ethical Standards Committee (RUESC).

In signing this, you also give me permission to share and publish the findings of my research.

Thank you.
Mrs Cobbing (email address supplied)

CONSENT FOR PARTICIPATION IN MRS COBBING'S RESEARCH PROJECT:

Please mark the applicable boxes (□):

I, ..., understand what I have read above and

□ will allow Mrs Cobbing to use the responses that I give in tests and examinations for the rest of my time at school as part of her data collection

□ agree to participate in a revision programme and allow Mrs Cobbing to use the responses that I give in the pre-intervention test and the post-intervention test as part of her data collection

□ would be willing to be interviewed about my understanding of physics and will allow Mrs Cobbing to use my responses as part of her data collection.

SIGNED: .... DATE: ....

Please ensure that covering letters and consent and assent forms are written in appropriate language and are complete and accurate. If verbal rather than written informed consent is to be obtained, then please upload written transcripts of the verbal information to be provided. As it is customary to obtain written informed consent, applications that deviate from this will have to be justified. Justifications for not obtaining written informed consent must be uploaded in Section H: Additional Documentation. Failure to provide sufficient justification is likely to have a negative impact on the outcome of the review.

Select up to 15 files to attach. You have attached 2 files (27.23 KB). You may add up to 13 more.

17.2 Describe the process by which consent to participate in the research will be negotiated and obtained *

At [School A] and [School B], I will explain to all the science classes what research I am conducting and the intended benefits of participation. I do not believe that addressing the class as a whole will put individuals under pressure to participate. I will invite students to participate and ask that they give their consent on the forms that I have provided. I will email the letter attached to parents, asking them to consider giving their consent and return the form. As stated in the letter, participants may withdraw at any stage.

At other schools, I will ask the class teacher to invite students to participate in the intervention.

Please be aware that coercion is a concern for research ethics review committees. For example, academics often recruit student participants and when their participation is tied to grades and/or where there is no opt-out option (or where opting out has a detrimental impact) an element of coercion and conflict of interest exists.

Limit: 2000 words

17.3 How will participants be contacted and notified about the research? *
The opportunity to participate will be offered in class.

In institutional settings, and/or where clear power differentials exist, research ethics review committees generally prefer indirect (e.g. telephone, email, letter) to direct interpersonal recruitment strategies.

If you answer this question by saying, for example, that you will contact participants via email to notify them about the research then you will have to explain how you will obtain their email address. Please ensure that these actions do not contravene provisions in the POPI (Protection of Personal Information) Act.

Limit: 1000 words

17.4 Will any sort of public notice be used to advertise the research to potential participants and/or gatekeepers and/or legal guardians? *

- (•) No
- ( ) Yes

Examples of public notices include poster advertisements placed in the public domain, email advertisements, advertisements posted on social media or other publically accessible online platforms.

17. 5 Is the information about the study provided to participants prior to obtaining their consent complete and accurate? *

- ( ) No
- (•) Yes

18. Will any of the information be obtained from, or pertain to, people who may be considered vulnerable? *

- ( ) No
- (•) Yes

Vulnerable individuals are people who are considered to be more susceptible to harm and/or unable, or less able, to protect themselves. It typically refers to people under the age of 18 years and those whose decisional capacity is diminished. However, it also commonly includes individuals and communities with limited resources, as well as individuals in subordinate or dependent relationships (e.g. student, patient, employee), and individuals dependent on healthcare or social assistance.

18.1 Which measures will be in place to ensure that vulnerable individuals are not exposed to additional risk or harm as a result of this research? *

Participation in the interview and in the use and evaluation of resources will be entirely voluntary. The examinations and tests will happen regardless of my research and are always treated sensitively.

Conducting research with - or about - vulnerable people requires special care to be taken to avoid any additional risk of harm as a result of the research

Limit: 2000 words

SECTION C: RISKS AND BENEFITS OF THE RESEARCH

The ethics committee must evaluate the potential risks associated with doing the research, assess the probability of the risk occurring and the magnitude of harm that may result. On the basis of this, the committee must then judge whether the anticipated benefits justify inviting participants to undertake the risks. The ethics committee cannot approve research in which the risks are judged unreasonable in relation to the anticipated benefits.

19. Does this research pose any risk of harm, embarrassment or offence, however slight or temporary to participant(s) and/or any third parties and/or to a particular social group or institution or a community at large? *

- ○ No
- ◉ Yes

If an applicant indicates that the proposed study poses no risk, but the committee can identify potential risks, then this is likely to have a negative impact on the outcome of the review.

The task is to show that you have given some thought to the sorts of risks that may arise in the process of doing the research and can identify those which, however unlikely or improbable, may possibly occur.

Please note that ethics review committees are required to give additional scrutiny to research that involves more than minimal risk. In the Common Rule minimal risks are defined as “the probability and magnitude of harm or discomfort anticipated in the research are not greater in and of themselves than those ordinarily encountered in daily life or during the performance of routine physical or psychological examinations or tests”. These provisions can be differently interpreted and applicants are advised to anticipate this in their responses to the questions that follow.

19.1 Describe the nature of the risks involved: *

Assessment through tests and examinations is a normal and, at present, unavoidable part of high school. These are written by all students and often are stressful and difficult for students and pose a risk of embarrassment.

However, it is the assessment process and not my research that poses a risk of embarrassment. My analysis of the results, performed confidentially after the usual marking process and with no comparative feedback to students, should have no effect whatsoever on students and will thus not increase the risk of embarrassment from assessment. I have done similar analysis since 2012 to inform my teaching and the students have probably not been aware of this. As my analyses will look at trends and patterns, no individual results will be included.

Those students who choose to participate in the revision intervention will see their own results as part of the learning process, but these will only be available to themselves and me.

Those students participating in the interview process may feel embarrassed if they are unable to answer the questions that I ask.

There are different kinds of harm that research occasions, these include, but are not limited to: physical harm (e.g. injury, illness, death), psychological harm (e.g. embarrassment or offence), social harm (e.g. stigmatisation), economic harm (e.g. financial loss/costs), legal harm (e.g. prosecution), and harm to the dignity of persons (e.g. discrimination).

These risks can arise both directly and indirectly as a result of the research. For example, asking participants to discuss sensitive information (e.g. relating to political opinions, religious beliefs, their health or sexual life) could cause them to experience psychological discomfort. Furthermore, while research can have obvious benefits for some, it can also jeopardise the wellbeing or social standing of others.

The risks vary in terms of type, probability, and magnitude from one project to another.

Limit: 1000 words

19.2 Which remedial measures will be in place in the event such risks occur? *

As the examinations and tests are not a result of my research, I cannot plan to avoid all embarrassment associated with these assessments.

If students are concerned or embarrassed about my use of their responses to test or examination questions, I will reassure them that they will be used entirely anonymously.

Should students be embarrassed about their responses in the pre- and post-intervention tests, I will reassure them that the results of their assessments and their responses are available only to myself and them and I will encourage them to see it as a learning experience.

If students are embarrassed or uncomfortable when they cannot answer a question in the interview, I will rephrase the question or move on, reassuring them that the interview is a process to help me better understand how they learn and there are no incorrect answers.

This question requires applicants to describe the measures that will be in place to respond in the event such risks occur.

Limit: 1500 words

19.3 What provisions will be made to minimize the potential of these risks occurring *

I will ensure anonymity in my capturing of test and examination responses and will ensure that my data are stored securely.

I will use Google Forms to administer the pre- and post-intervention tests so that students are able to access the tests individually in privacy from their own devices or from a computer on their own.

I will conduct the interviews myself, in a space where students' responses cannot be heard by others.

This question requires applicants to describe what will be done to reduce the potential for such risks occurring in the first place.

Limit: 2000 words

19.4 Has the person administering the project previous experience with the particular risk factors involved? *

- ○ No
- ◉ Yes

20. Which benefits, if any, are expected to accrue to individual participants, and/or third parties, and/or a particular social group and/or institution and/or community or society at large as a result of the research? *

I hope that my current and future students will benefit from the resources that I develop for this study, which will be designed, tested and adjusted to improve understanding. As well as improving their understanding of physics concepts, my intervention will be designed for students to use on their own, without input from a teacher. My intention is to nudge students to take greater responsibility for building their own understanding (using resources provided), which will help them become more independent in their learning. A better understanding of physics concepts, especially if constructed for themselves, should also improve their confidence in the subject. This resource should also be able to be used as a stand-alone intervention by students who do not have access to a teacher or who have missed lessons.

I strongly believe that my study of poor conceptual understanding, its origins and potential methods to improve it, will improve my teaching practice, making my teaching more intentional, again benefitting current and future students. If I am able to share my findings, I hope that they will be of value to other science teachers who may be able to draw from the successful methods mentioned and so benefit a wider community of practice.

It is important to give adequate attention to this question. The committee is required to assess whether or not the potential benefits and risks are reasonably balanced. If the research poses potential risks without (or with very little) potential benefits then this is likely to have a negative impact on the outcome of the review.

If the proposed research does not hold out the prospect of direct benefit for the research participants, then it must be justified in relation to the expected benefits to society. Once again, the committee is tasked with assessing the reasonableness of the risk/benefit balance.

Limit: 2000 words

SECTION D: CONFLICTS OF INTEREST

Conflicts of interest are not limited to financial interests – they include any circumstance that could result in the perception of undue influence or coercion. For example, if a researcher wishes to recruit a participant who is also a student, an employee, a colleague or a subordinate of the researcher, the potential for coercion exists.
While the researcher may be careful to avoid potentially coercive behaviour, the very nature of the relationship with the participant can create the appearance of coercion.
Researchers who do wish to include these groups as participants must give special consideration to the potential risk of harm that arises as a result.

21. Do you or other researchers involved in the project have a potential or actual conflict of interest in this project’s conduct or outcomes? *

- (•) No
- ( ) Yes

SECTION E: DATA MANAGEMENT, STORAGE AND USE

Please ensure that information about how anonymity and confidentiality will be managed in the handling and storage of data has been communicated to, and consented to by participants as appropriate, and that this is reflected in information letters and consent and assent forms. Failure to attend to this is likely to have a negative impact on the outcome of the ethics review.

22. How will you ensure that information is captured, transferred and stored securely? *

Data Storage:

All digital data (marksheets, Google Form test responses, response summaries, interview transcripts and all other components of this study) will be stored in my personal folder (Home Drive) on the school network. This folder is accessible only by me, using a password. I will back up my data to my Google Drive folder, again accessible only by myself, using a password.

Hard copies of data will be kept in document holders in a secure cupboard in my locked classroom.

Data Collection and Processing:

Please note: In the declaration on this application, I am asked to sign that the information collected will be used only for purposes for which approval has been obtained. I will be analysing data collected through normal assessment which will be used within the school context for reporting, remediation, assessment, etc. My declaration thus refers only to the data collected explicitly for this study (the interviews and the pre- and post-intervention test data and responses).

I will collect tests and examinations and mark them as usual.

For tests, we have begun to produce an examiners' report for each test, highlighting common errors. This draws from common mistakes and does not include individual's responses.

For examinations, I capture the results per question and the responses to multiple choice questions in a spreadsheet as a matter of course and these results are saved on a secure, password-protected folder on the school network, accessible only by the Physical Sciences Department teachers at [School A] and [School B]. We rarely print these analyses, but if they are printed for report-writing purposes, they are filed in my Teaching Admin file, stored behind my desk in my secure classroom, which is used only by myself.

For the purposes of this study, as soon as the marking and moderation process is complete, I will save a copy of the spreadsheet of results and responses in my personal folder with individual names removed. I will leave the gender of the individuals in this spreadsheet in case I want to study this variable at a later date. I will use this spreadsheet for all subsequent data analysis.

Original tests and examinations will be returned to students, with parts that I wish to use in my research captured anonymously before they are returned and stored securely (as detailed above). Grade 12 assessments are not returned, but are all kept to be included in a final School Based Assessment Portfolio and so are filed in portfolio files in their teachers' classrooms. This is our normal procedure and has proved to be secure.

Interviews will be recorded digitally and then transcribed. The digital records of the interviews and the typed transcripts will be saved in my personal folder on the school network. Those students interviewed will be given the opportunity to read through the transcript of their interview to confirm that they are happy with the content.

Pre-intervention tests and post-intervention tests will be conducted using Google Forms for students [of The Schools] and so responses will be captured digitally. I will use hard copy forms of the same multiple choice assessments for neighbouring schools where students may not be familiar with Google Forms or have easy access to the tests.

Destruction of data:

I will store the data as described above for 5 years after completion of this study and then destroy all raw data generated for this study. This will be done by deleting all digital copies of the data and shredding the hard copies filed.

Describe the form of data handling and storage arrangements throughout the project: at collection stage; when used/disclosed; when stored; and when destroyed. Up until destruction, be clear about describing whether data will be non-anonymised (openly linked to the individual(s) who provided them and so fully identifiable), pseudo-anonymised (potentially linkable/identifiable), or completely anonymised (cannot be linked back to an individual/individuals by researchers, non-identifiable). Please explain if translators and or transcribers will be given access to the data. If so, upload templates/draft copies of the Confidentiality Agreements that they will be required to sign in Section H: Additional Documentation.

Limit: 2000 words

SECTION F: FEEDBACK TO PARTICIPANTS AND STAKEHOLDERS

Please ensure that information about how the project outcomes will be disseminated is communicated to, and consented to by participants (and, where necessary, community stakeholders) as appropriate, and that this is reflected in the information letters and consent and assent forms. Failure to do so may have a negative impact on the outcome of the ethics review.

23. How will you disseminate and feedback project outcomes at the end of the research? *
I hope that my findings will be useful enough to warrant publication and sharing. The extent of this sharing will be determined by the perceived value of the outcomes.

I will make the findings available to the students of [The Schools] via electronic file sharing and will share the findings with the teachers and schools who participated.

Describe your plans with respect to participants and community partners as well as public dissemination plans, e.g. publication in academic journals and conference presentations.

Limit: 1000 words

Please confirm each of the statements below: *

- ☑ All of the information provided in this application is complete and accurate
- ☑ This research will not proceed before ethical approval is obtained
- ☑ Only authorised persons will have access to the data

- ☑ The information collected will only be used for the purposes for which approval has been obtained
- ☑ This research project will only be conducted if funding is adequate to enable it to be carried out according to good research practice and in an ethical manner
- ☑ Any and all additional information required by the RUESC either before approval is obtained or as the research progresses will be provided immediately upon request
- ☑ The RUESC will be immediately notified in writing of any proposed change to the project which would in any way alter the risks associated with doing this research and await approval before proceeding with the proposed change
- ☑ The RUESC will be immediately notified in writing of any proposed change to the researchers involved in the project and will be provided the names and contact details of new and/or departing researchers
- ☑ The RUESC will be immediately notified in writing and within seven days of any serious adverse event that occurs in the course of the research

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Section H: Additional Documentation

APPENDIX A.6: Email Correspondence with IEB Assessment Specialist regarding the use of IEB IDC data

From: Helen Sidiropoulos <email address>
Sent: Thursday, March 8, 2018 12:45 PM
To: Kate Cobbing <email address>
Subject: RE: IDC forms

Dear Kate

The full IDC report is sent to schools with the release of the results. I have attached 2017 – we have several but not 10 years back. The IDC and the averages are in the public domain – so as long as correctly referenced may be used for research purposes. If published in any way and IEB mentioned we require right of comment and reply before publication. mentions IEB
Regards
Dr Helen Sidiropoulos
Assessment Specialist

From: Kate Cobbing <email address>
Sent: Thursday, 08 March 2018 12:36 PM
To: Helen Sidiropoulos
Subject: IDC forms

Dear Helen

I hope that you are well and I hope that you don't mind me emailing you to ask this.

I am doing a research project and want to look at concepts in physics that are poorly understood. I have an idea from my own teaching and I have downloaded the examiners' reports from the past 10 years, but also hoped to look at the IDC info.

I cannot find any info (averages per question) on the website / document library, which means I need to ask you two things:
- is it there and I am looking in the wrong place?
- is this info available to all? (if not, I am not sure that I can use even those years that I have, as I have to have consent to use any such info that is not generally available, I think) I have the IEB averages for most years, I think, filed with the exams with our own IDC sheets.

Thank you so much.

Regards
Kate

APPENDIX A.7: Correspondence regarding the use of historically collected, anonymous information

From: Prof. Joanna Dames <j.dames@ru.ac.za>
Sent: Sunday, July 29, 2018 9:17 AM
To: Joyce <J.Sewry@ru.ac.za>
Cc: Jennifer Williams <Jennifer.Williams@ru.ac.za>; Kate Cobbing <email address >
Subject: Re: FW: Gatekeepers' Permission

Dear Joyce

This is a standard clause on the letters. Use of the data mentioned in the proposal is approved.

Jo

RHODES UNIVERSITY
Where leaders learn

Prof Joanna Dames
Department of Biochemistry and Microbiology
Deputy Dean: Science Faculty
t: +27 (0) 46 603 8443 f: +27 (0) 46 603 7576 cell: 083 636 0706
Biological Science Building, Cnr Lower University and Artillery Rds, Grahamstown, 6139
PO Box 94, Grahamstown, 6140, South Africa
http://www.ru.ac.za/bm/people/academicstaff/dames
Fax to Email: 0836360706
Alternative email: jo@mycoroot.com
www.mycoroot.com

On Thu, 26 Jul 2018 at 12:11, Joyce Sewry <J.Sewry@ru.ac.za> wrote:

Dear Jo

On the second page of this ethics approval it states that ethics approval is not granted retrospectively. I assume that this is a standard statement?

Please will you confirm that Kate may use the anonymous exam data gathered previously, as per her application?

Thanks

Joyce

Acceptable file types: pdf, doc, docx, txt, rtf, jpg, gif, tiff, png, wpf, odt, wpd, svg.

1

KCobbing_Correspondence_about_funding.pdf

3

KCobbing_Letter_to_RUESC_re_historically_collected_anonymous_data_-_Kate_Cobbing.pdf

4

KCobbing_Letter_to_RUESC_supporting_use_of_MCQ_data_from_supervisors.pdf

5

KCobbing_Sample_of_anonymous_data_collected_MCQ.pdf

6

KCobbing_Sample_of_anonymous_data_collected_Q_breakdown.pdf

Choose Files

Up to ten (10) additional documents can be uploaded. If additional documentation is required and exceeds this number then please liaise with the RUESC administrator. Please ensure that the documents are appropriately labelled and identifiable. E.g. JMarx Research Proposal, JMarx Transcription Confidentiality Agreement. Documentation that is not appropriately labelled and identifiable will result in processing delays

APPENDIX B: Grade 12 2018 Tutorial and Evaluation Form on Electric Circuits (as done on Google Forms)

Grade 12 Electric Circuits Tutorial

This form will guide you through some questions to establish your understanding of certain concepts, then provide videos, notes and questions to help improve your understanding before presenting you with more questions to check your understanding.

Your email address (**k.cobbing**[redacted]) will be recorded when you submit this form. Not **k.cobbing**? Sign out

* Required

1. **So far I have prepared for the test by (you can choose multiple options)** *

   Check all that apply.

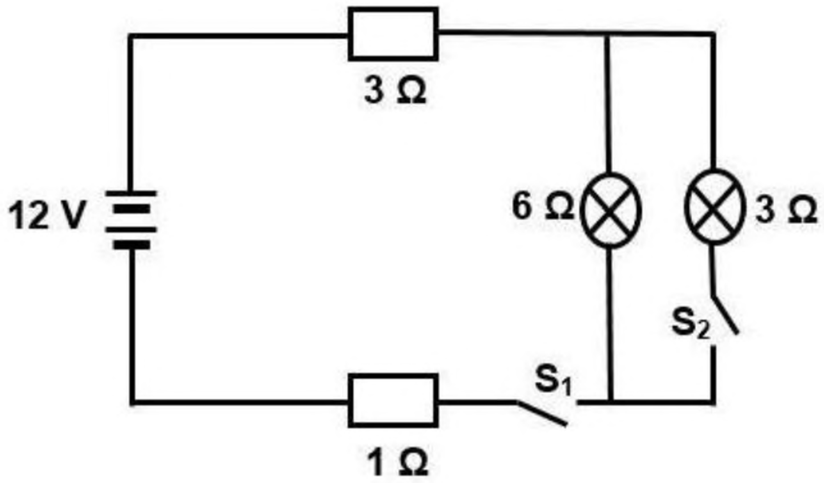
   - [ ] reading through my notes
   - [ ] learning my definitions
   - [ ] summarising notes
   - [ ] working through the March 2018 circuits test
   - [ ] completing part of the Revision Pack
   - [ ] completing the whole of the Revision Pack
   - [ ] practicing past tests (from Student Drive)
   - [ ] attending Physics Support
   - [ ] watching online videos
   - [ ] working with a friend
   - [ ] seeing a tutor
   - [ ] I have yet to start preparing

2. **I can answer electric circuit questions**

   Mark only one oval.

	1	2	3	4	5	
Very confidently	⬭	⬭	⬭	⬭	⬭	Not at all confidently

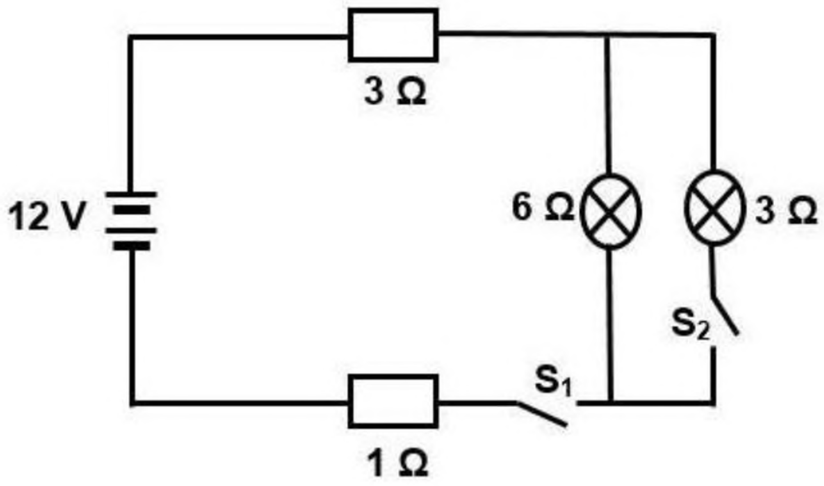
3. **When S1 and S2 are both open, what will be the current through the 1 ohm resistor?** *



Mark only one oval.

- 0 A
- 1.2 A
- 2 A
- 12 A

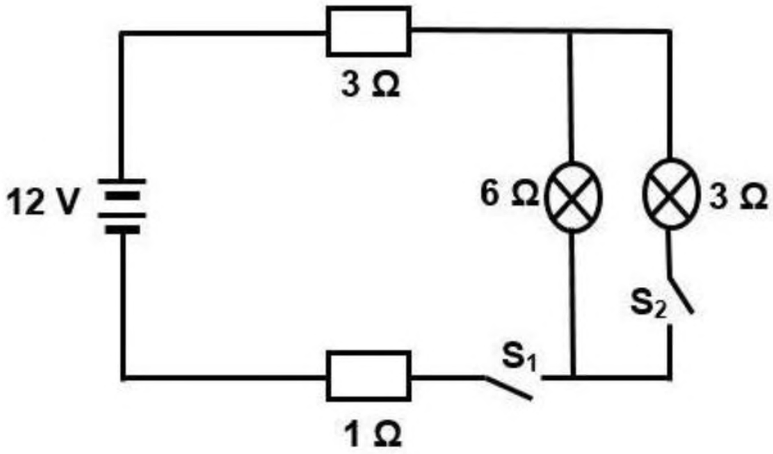
4. **When the switch S1 is closed, but S2 remains open, what will be the current through the 1 ohm resistor?** *



Mark only one oval.

- 0 A
- 1.2 A
- 2 A
- 12 A

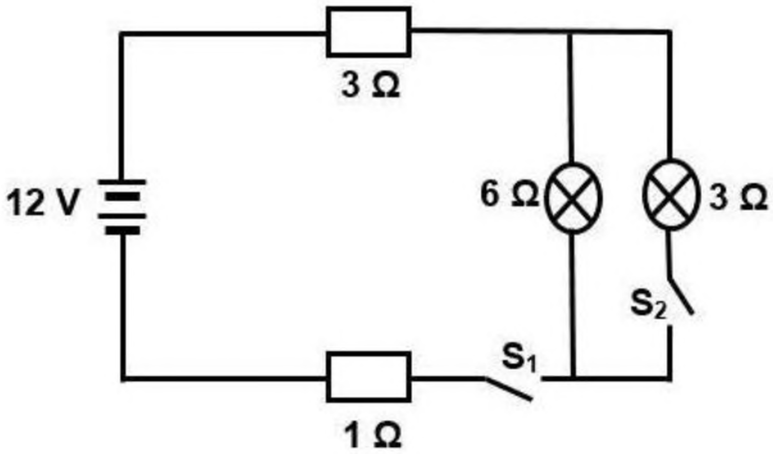
5. **When switches S1 and S2 are closed, which of the following statements is true:** *



Mark only one oval.

- The current in the 3 ohm bulb is greater than in the 6 ohm bulb.
- The potential difference across the 3 ohm bulb is greater than across the 6 ohm bulb.
- The current in the 6 ohm bulb is greater than in the 3 ohm bulb.
- The potential difference across the 6 ohm bulb is greater than across the 3 ohm bulb.

6. **When both switches S1 and S2 are closed, the greatest voltage will be across the**



Mark only one oval.

- 3 ohm resistor
- 6 ohm bulb
- 3 ohm bulb
- 1 ohm resistor

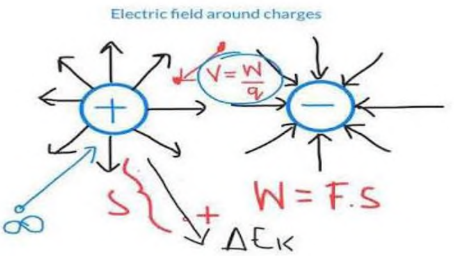
Resources

Here are some links to videos explaining concepts. Watch them - or some of them - and then answer the questions at the end of the quiz.

7. **Watch the video link below on electric circuits- terminology. Please provide feedback below to help me improve the video. I found this video**
Mark only one oval.

	1	2	3	4	5	
Very helpful	◯	◯	◯	◯	◯	Confusing

Electric Circuits - Terminology

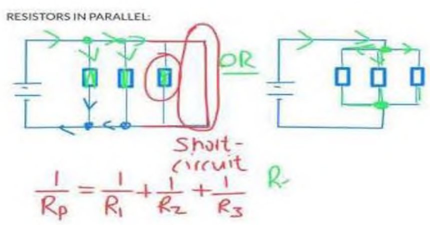


http://youtube.com/watch?v=Ve_ZeSo6Aw0

8. **Watch the video link below on electric circuits- Calculations in Simple Electric Circuits. Please provide feedback below to help me improve the video. I found this video**
Mark only one oval.

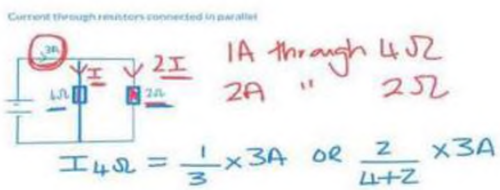
	1	2	3	4	5	
Very helpful	◯	◯	◯	◯	◯	Confusing

Electric Circuits - Simple Calculations (Resistors)



http://youtube.com/watch?v=LN_dL5lZSv4

Electric Circuits - Simple Calculations (V = IR)

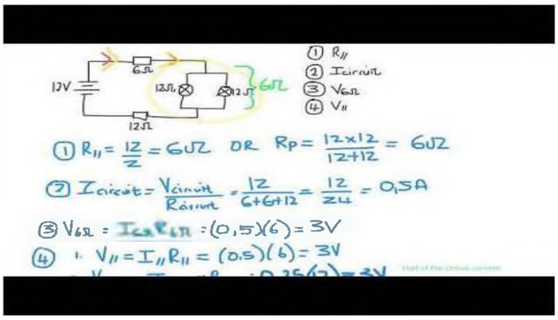


http://youtube.com/watch?v=_AI8G_ryeZ8

9. **Watch the video link below on electric circuits- Worked Examples (Simple Electric Circuits). Please provide feedback below to help me improve the video. I found this video**
Mark only one oval.

	1	2	3	4	5	
Very helpful	⬭	⬭	⬭	⬭	⬭	Confusing

Electric Circuits - Worked Examples

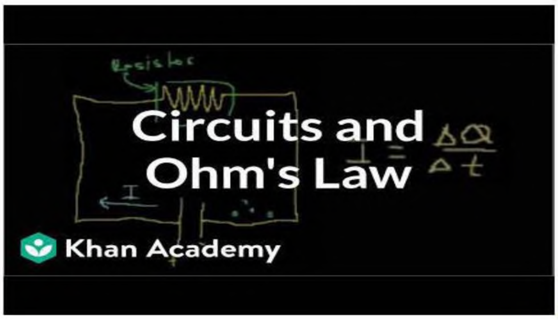


http://youtube.com/watch?v=_P_e0f9vVCc

10. **Watch the video link below on electric circuits from Khan Academy. Please provide feedback below to give me an idea of whether this was useful. I found this video**
Mark only one oval.

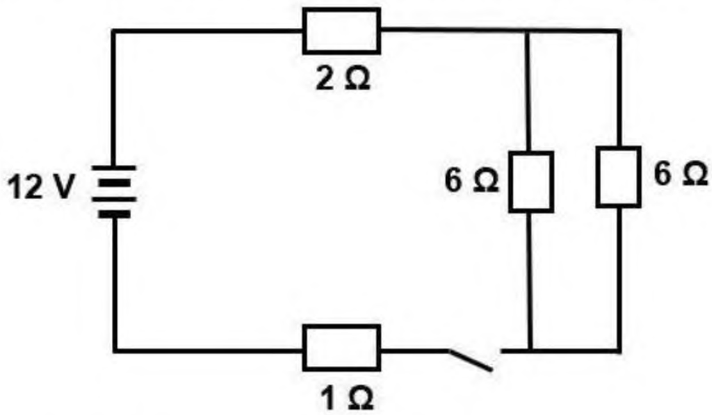
	1	2	3	4	5	
Very helpful	⬭	⬭	⬭	⬭	⬭	Confusing

Khan Academy video on Ohm's Law and current



http://youtube.com/watch?v=F_vLWkkOETI

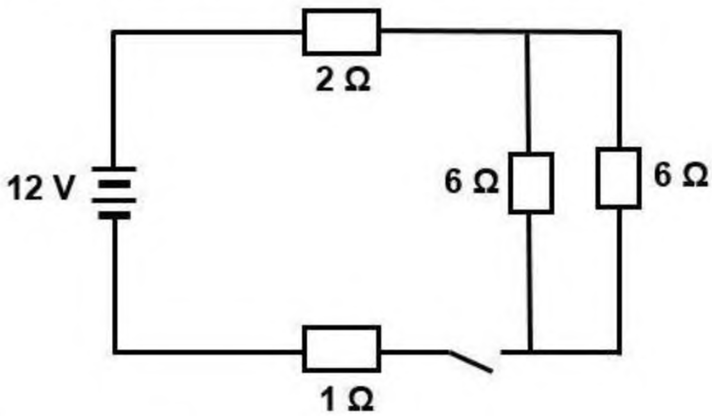
11. **The current through the 1 ohm resistor when the switch is closed is**



Mark only one oval.

- 0 A
- 1 A
- 1,2 A
- 2 A

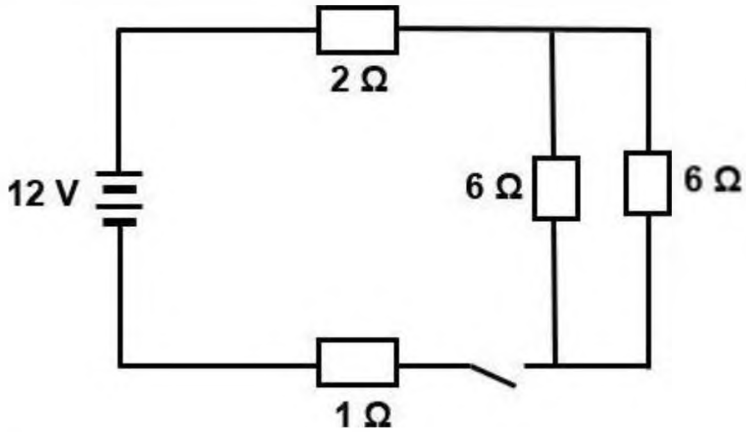
12. **When the switch is closed, the current in the 2 ohm resistor is**



Mark only one oval.

- 0 A
- 1 A
- 1,3 A
- 2 A

13. **When the switch is closed, the largest voltage will be across the**



Mark only one oval.

- ◯ 2 ohm resistor
- ◯ the 6 ohm resistors in parallel
- ◯ the 1 ohm resistor

14. **I watched the following videos**

Check all that apply.

- ☐ Electric Circuits - Terminology
- ☐ Electric Circuits - Simple Calculations (Resistors)
- ☐ Electric Circuits - Simple Calculations (V = IR)
- ☐ Electric Circuits - Worked Examples
- ☐ Khan Academy video on Ohm's Law and current

15. **After watching these videos and answering the questions,** *

Mark only one oval.

- ◯ I feel confident about the concepts in the electric circuit section
- ◯ I understand the electric circuit section better than I did before
- ◯ I understand some of the concepts better than I did before
- ◯ I still don't understand the concepts well (if this is the case, please answer the next question)

16. **If this process helped your understanding, tick the reasons why you think it helped**

Check all that apply.

- ☐ I missed some lessons and so had gaps in my understanding
- ☐ There were some concepts that I just didn't get the first time round
- ☐ I needed to hear the concepts explained again
- ☐ I needed to spend more time on the concepts - now that I have spent time, they make sense
- ☐ Other: ____________________

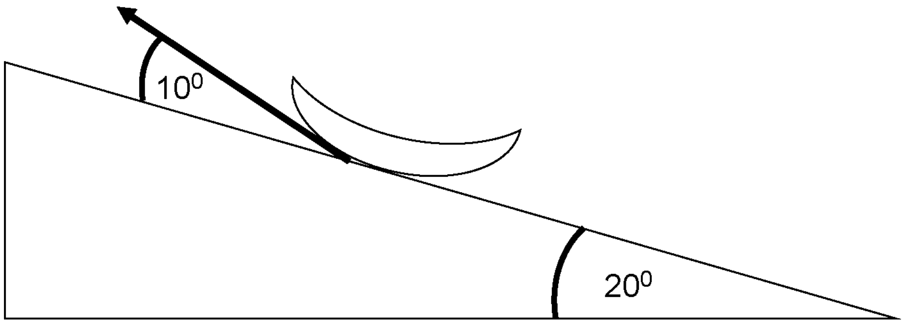
17 **If you need more help, please give your name and list any questions that you still have, so that I can help you further.**

APPENDIX C: Grade 12 Examination August 2018 (preliminary assessment of student understanding)

QUESTION 3 NEWTON'S LAWS

On arrival at the SKA site, the dish is offloaded from the back of the truck by sliding it down a ramp which has a rough surface at 20° to the horizontal. The mass of the dish is 30 tonnes. (1 tonne = 1000 kg)

The dish is kept stationary by a cable which is at 10° to the ramp.
The tension in the cable is 60 000N.



3.1 Draw a labelled free-body diagram of all the forces acting on the dish. (4)

3.2 Firstly, calculate the magnitudes of the components of the weight of the dish which are:

3.2.1 parallel to the ramp (to the nearest newton) (2)

3.2.2 perpendicular to the ramp (to the nearest newton). (2)

3.3 Secondly, calculate the magnitude of the perpendicular components of the tension in the cable. (4)

3.4 Calculate the frictional force acting up the slope. (4)

3.5 Hence, find the co-efficient of friction that is acting between the ramp and the dish. (answer to two decimal places) (4)

The cable snaps and the dish accelerates down the slope for 36 m in 6 s.

3.6 Calculate the magnitude of the acceleration of the dish as it slides down the ramp. (3)

3.7 Define *Newton's second law*. (2)

3.8 What net force is the dish experiencing? (3)

3.9 Calculate the frictional force acting on the dish as it slides down the ramp. (4)

3.10 Explain why the frictional force is different from the value you got in Q 3.4. (2)

3.11 State the *Work-Energy Theorem.* (2)

3.12 Use the Work-Energy Theorem to calculate the velocity of the dish at the bottom of the ramp. (4)

[40]

APPENDIX D: Grade 11 August 2018

(preliminary assessment of student understanding)

QUESTION 5 GRASS COURT

Wimbledon is played on grass courts, which are acknowledged to be the fastest surface for tennis, but also can be very slippery underfoot.

Angelique Kerber (who went on to win the women's final in 2018) is running at 3 m/s and stops suddenly. As she stops running, her foot slides across the court, bringing her to rest. Her mass is 65 kg and the coefficient of sliding (dynamic) friction between her shoe and the grass is 0,35.

5.1 State *Newton's second law.* (2)

5.2 Calculate the frictional force acting on Kerber as she slides. (4)

5.3 Calculate the magnitude of Kerber's acceleration as she comes to rest. (3)

5.4 How far will she slide? (3)

To prepare them for play, the courts have to be rolled flat using a roller, such as the one shown alongside.

Image from https://www.spyn.co/blog/tennis-ball-aerodynamics/

The roller is pulled across the court with a <u>horizontal force</u> at a constant velocity.

5.5 Draw a labelled free-body diagram of the forces acting on the roller as it is being pulled as described. (4)

5.6 The picture below shows someone rolling a grass court with a roller, applying a pushing force at an angle to the ground. Explain why it would be more effective to roll the court like this than pulling the roller with a horizontal force, as described above. No calculations are necessary. (3)

Image from https://grand-slam.com.au/shop/shop-fullwidth/

19 marks

QUESTION 6 STRAWBERRIES AND CREAM

A trolley of strawberries and cream (a Wimbledon tradition) is pushed up a ramp, which is at an angle of 8^0 to the horizontal.

The trolley (and its contents) has a mass of 20 kg. The trolley is pushed half way up the ramp and then the wheels are locked, so that they cannot turn. The coefficient of maximum static friction is 0,9 for the wheels on the ramp.

6.1 Draw a free-body diagram of the forces acting on the trolley as it is stationary on the ramp. (3)

6.2 Determine the magnitude of the perpendicular components of the weight of the trolley. (4)

6.3 Calculate the maximum frictional force. (4)

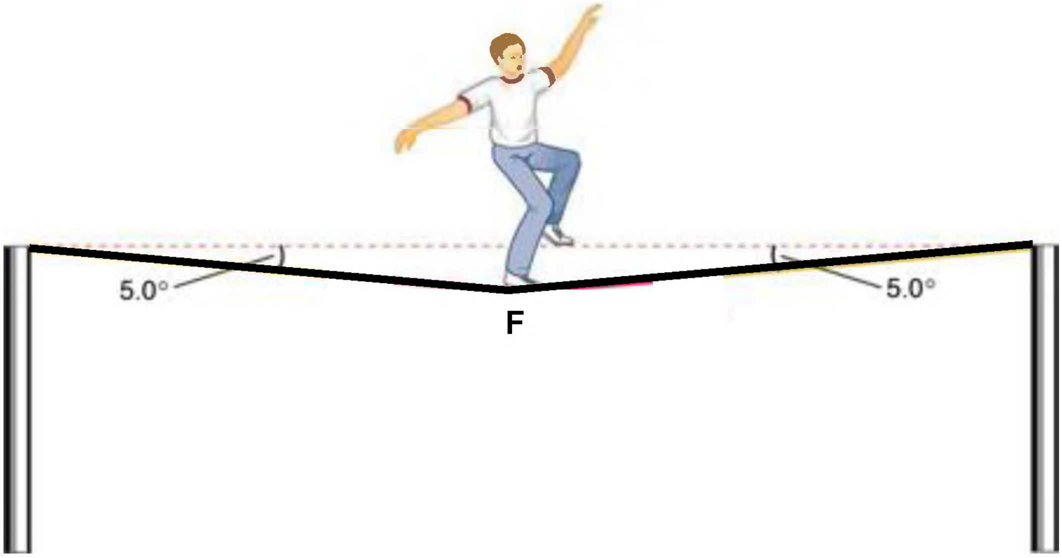
The wheels are now unlocked and the trolley is pushed up the ramp. It experiences a frictional force of 30 N.

6.4 What minimum force is needed to push the trolley up the ramp at constant velocity? (4)

15 marks

QUESTION 7 TENNIS NET

All tennis nets sag a little in the middle due to their mass, but the angle of "sag" is so small that it is more interesting to look at a tightrope walker:



The mass of the tightrope walker is 75 kg. The rope makes an angle of 5^0 with the horizontal.

7.1 Determine the magnitude of the tension in the rope. (4)

7.2 The distance between the poles is 11 m. How long is the stretched rope (from pole to pole)? (3)

7 marks

APPENDIX E.1: Revision Resource on Forces, Tension and Inclines (VERSION 1) Iteration 1 – Grade 12 September 2018

MATRIC REVISION CAMP 2018

PHYSICS: VECTORS

CONTENT FOCUS (from the SAG document):

Vectors

- Define a vector as *a physical quantity that has both magnitude and direction* and give examples
- Define a scalar quantity as *a physical quantity that has magnitude only* and give examples
- Define resultant vector as *the single vector which has the same effect as the original vectors acting together*
- Determine the resultant vector of any two vectors
- Determine two perpendicular components of any vector (e.g. force at an angle, weight on an inclined plane)
-

Force Diagrams, Free Body Diagrams

- Draw a labelled force diagram by representing the object(s) of interest with all the forces acting on it (them) drawn in as arrows. The forces must be named (e.g. Weight, normal, force A on B, friction, air resistance)
- Draw a free-body diagram by drawing the object of interest as a dot and all the forces acting on it drawn as arrows pointing away from the dot. The forces must be named (e.g. weight, normal, force A on B, friction, air resistance)
- Resolve two-dimensional forces into parallel (x) and perpendicular (y) components (e.g. the weight of an object with respect to an inclined plane)
- Calculate the resultant or net force in the x-direction as a vector sum of all the components in the x-direction and the resultant or net force in the y-direction as a vector sum of all the components in the y-direction

Newton's Second Law

- State Newton's second law: *When a net force, F_{net}, is applied to an object of mass, m, it accelerates in the direction of the net force. The acceleration, a, is directly proportional to the net force and inversely proportional to the mass*
- Solve problems using
  $F_{net} = ma$
- Apply Newton's laws to a variety of equilibrium and non-equilibrium problems.
  (e.g. Use Newton's second law to solve problems including an object moving on a horizontal/inclined plane (frictionless and rough), vertical motion (e.g. Rockets, hoisting masses etc.) and also two-body systems such as two masses joined by a light (negligible mass) string moving in a straight line either vertically or horizontally)

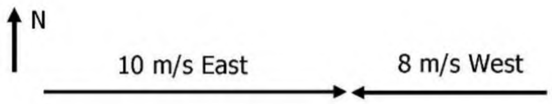
Work – Energy Theorem

- State that the *work done by a net force on an object is equal to the change in the kinetic energy of the object* – the work-energy theorem
- Apply the work-energy theorem to objects on horizontal and inclined planes (frictionless and rough)
- Kinetic energy of a system is increased when F_{net} is in the same direction as *s* or Δx
- Kinetic energy of a system is decreased when F_{net} is in the opposite direction to *s* or Δx

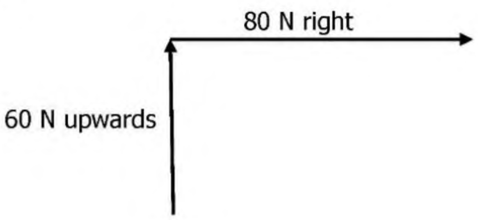
We can find a resultant vector of any vectors, by finding the vector sum of those vectors (*this means adding the vectors, taking into account their directions*):

1.

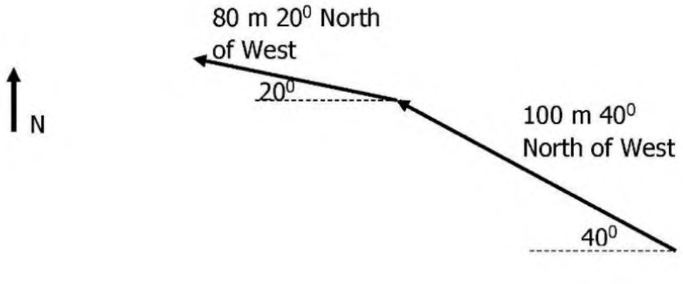
2.



3.



4.

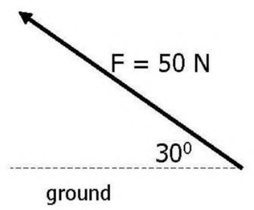


The last example is easy enough to draw, but how do you calculate the resultant? *We could use a scale to determine the resultant, but by the end of the next section, you will be able to calculate the resultant vector using algebra.*

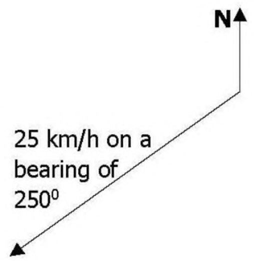
We need to be able to confidently resolve **<u>any vector</u>** into its components.

<u>Perpendicular components</u> are vectors (perpendicular to one another) that have the same effect as the resultant vector.

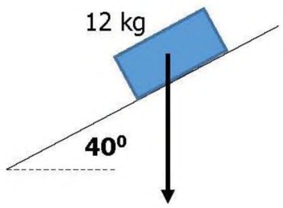
Example 1: Find the perpendicular components of a force applied at an angle:

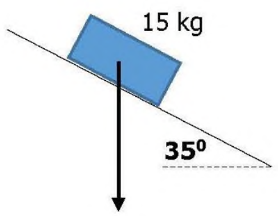


Example 2: Find the perpendicular components of a velocity at a given bearing:

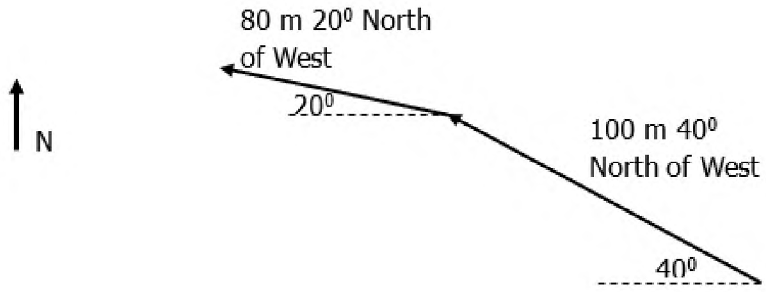


Example 3: Find the perpendicular components of the weight of an object on an incline:





So to find the resultant vector in the example on page 2, we could find the perpendicular components of each vector and add the *components* of the vectors to give the *components* of the resultant:



Remember:

- Newton's First Law: ***An object continues in a state of rest or uniform velocity unless acted on by an external net force.***

- When the net force is zero, the object can be described as being in EQUILIBRIUM.
- Any object that is not accelerating is in equilibrium, whether it is stationary or moving at a constant velocity.
- *If a body is in equilibrium, it does not necessarily mean that there are NO forces acting on it. It means that the NET FORCE IS ZERO – the forces balance each other.*

- Newton's Second Law (in terms of acceleration): ***When a net force is applied to an object, it accelerates in the direction of the net force. The acceleration is directly proportional to the net force and inversely proportional to the mass of the body.***

  $F_{net} = ma$ AND F_{net} = vector sum of all forces acting : $F_{net} = F_1 + F_2 + F_3 + ..$

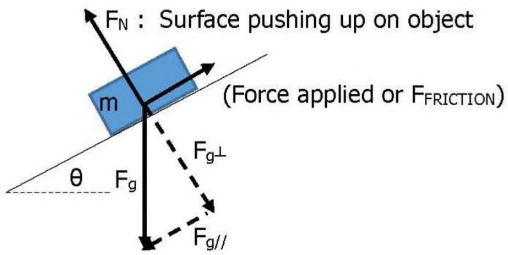
- You are finding a vector sum and so you must choose a positive direction and apply it.

- Always draw a free body diagram of the forces acting on the object or system that you are considering.
  - Your labels should always include what is exerting the force, on what and in what direction.

- The frictional force (F_F) due to a surface is the force that **opposes the motion** of an object.
  - The frictional force on an object acts parallel to the surface with which the object is in contact.
  - The actual (or minimum) frictional force is the frictional force acting on the object and can be determined using the vector sum of forces acting parallel to the surface.
  - Maximum static friction is the frictional force that must be overcome before the object will start to slide and can be determined using $F_{friction} = \mu_{s,\,max} \cdot F_N$

Inclined planes:

A reminder:



Weight is always vertically downwards, but it has perpendicular components:

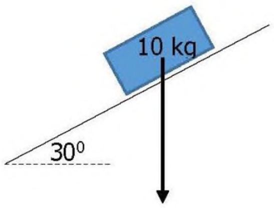
- $F_{g//}$: component of weight down the slope
- $F_{g\perp}$: object pushing on surface

The object is not accelerating perpendicular to the surface and so F_N and $F_{g\perp}$ will always be equal.

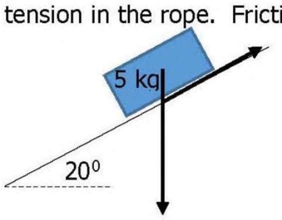
5

Inclined planes examples:

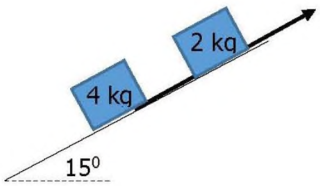
Example 1: Determine the F_{fric}^{max} if μ_s^{max} = 0,4 and the mass of the block is 10 kg.



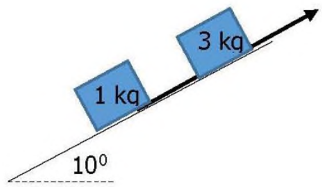
Example 2: A rope pulls the block (mass 5 kg) up the slope at a constant velocity. Determine the tension in the rope. Friction between the block and incline can be ignored.



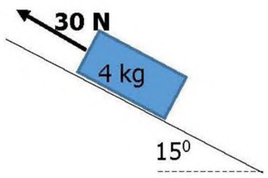
Example 3: Determine the acceleration of the two blocks, if they are pulled up the slope with an applied force of 20 N. Friction between the blocks and incline can be ignored.



Example 4: Determine the tension in the rope between the two blocks, if they are pulled up the slope with an applied force of 20 N. Friction between the blocks and incline can be ignored.



Example 5: The block shown is pulled up the slope with a force of 30 N. The block experiences a frictional force of 8 N. Determine the acceleration of the block.



Example 6: A car (mass 1000 kg) is **parked** on a 6^0 slope. What minimum frictional force must the car experience?

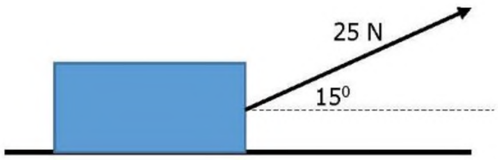
7

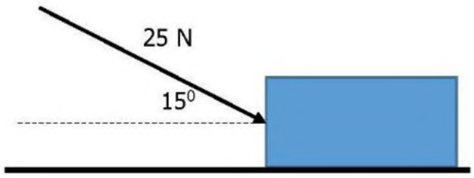
Example 7: A car (mass 1000 kg) drives **up** a 6^0 slope. The driving force applied by the engine is 1 500 N. Calculate the acceleration of the car.

Example 8: A car (mass 1000 kg) drives **down** a 6^0 slope. The driving force applied by the engine is 1 500 N. Calculate the acceleration of the car.

Forces applied at an angle:

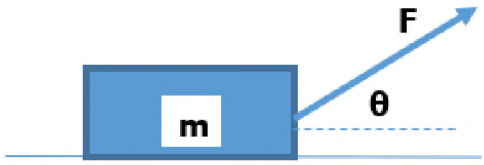
Determine the frictional force between the ground and the 10 kg box in each of these examples. The coefficient of maximum static friction is 0,8.





9

If this block is being pulled along at a constant velocity with force F, as shown. Determine μ.

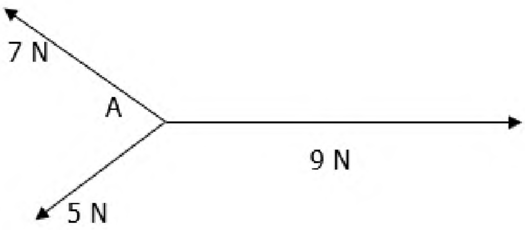


Equilibrant Force

The force that results in equilibrium. It is the force that "balances" the net force of the others.

Example:

Three forces keep a body in equilibrium at point A. If the force of 5N is suddenly removed, the magnitude of the **resultant** force exerted on the body at A will be



A. 7 N

B. 9 N

C. 5 N

D. 2 N

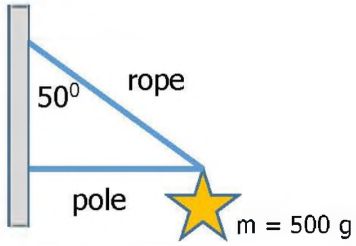
Equilibrium:

An object that is "hanging" or that is stationary, suspended by ropes or strings, is in equilibrium. This means that the forces or components of forces balance each other out.

The sum of the vertical forces (or components of forces) is zero and the sum of the horizontal forces (or components of forces) is zero.

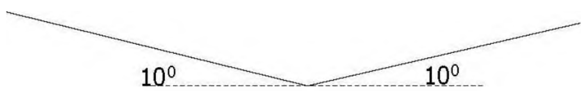
Examples:

1. A 500g decorative star is suspended by a rope from the side of a building, held away from the wall with a horizontal pole, as shown in the diagram. The rope makes an angle of 50^0 to the wall where it is tied on. Determine the tension in the rope suspending the star.

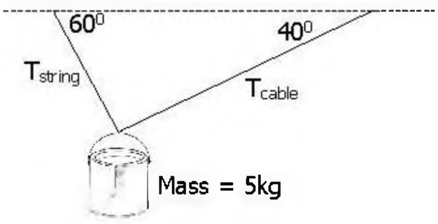


When there are two strings, each string supports half the weight:

2. A tight-rope walker (weight 500 N) is balancing on a piece of string. The angle that the string makes with the horizontal is 10^0. Determine the tension in the rope.



3. A can of paint is suspended using a cable and a string, attached to the ceiling as shown. The mass of the can of paint is 5 kg. Determine the tension in the string.

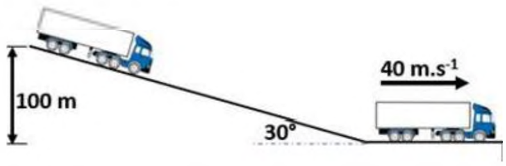


Work-Energy Theorem:

The work-energy theorem often uses your knowledge of vectors because it is the work done by the net force that results in a change in kinetic energy. So you may apply all that you have learnt above (not equilibrium!) to solve questions using the work-energy theorem.

Example of exam-type question:

A 10 000 kg truck starts rolling down the 30° incline from a height of 100 m above the level road below, reaching a speed of 40 $m.s^{-1}$ at the bottom of the hill.



1. Calculate the work done by friction on the truck as it moves down the incline. (5)

2. Calculate the frictional force acting on the truck as it moves down the incline. (4)

APPENDIX E.2: Revision worksheet 1 (VERSION 1)
Iteration 1 – Grade 12 September 2018

MATRIC REVISION CAMP 2018 - PHYSICS: VECTORS EXERCISES

ADDITIONAL EXERCISES TO PRACTICE VECTORS:
(All found in your books of past papers)

- Question 4.2 of 2017 IEB Exam
- Questions 2 & 4 of 2016 Supplementary IEB Exam
- Question 4 of 2016 IEB Exam
- Question 2 of 2015 Supplementary IEB Exam
- Questions 4.3, 4.4 and 5.2 of 2015 Supplementary IEB Exam
- Question 1.1 of 2015 IEB Exam
- Question 2.2 & Question 4.5 of 2014 IEB Exam
- Question 2.3 & Question 4 in 2014 Exemplar (NB 4.2.4)
- Question 1.10 of 2013 IEB Exam
- Question 2 of 2009 IEB Exam

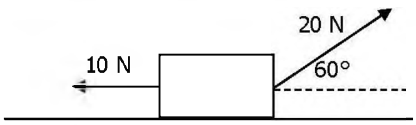
1.1 Two forces have magnitudes 3 N and 5 N. Which of the following is **not** a possible resultant force of these two forces?

A. 8 N
B. 2 N
C. 15 N
D. 5 N

1.2 Which statement is **true** for all objects in equilibrium?

A. The object is at rest.
B. The sum of the magnitudes of the forces acting on the object is zero.
C. The vector sum of the forces acting on the object is zero.
D. There are no forces acting on the object.

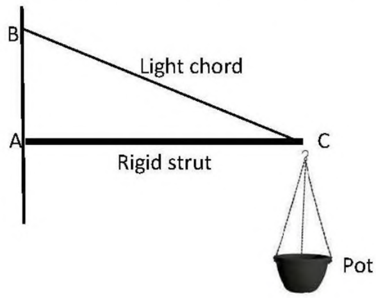
1.3 A block of mass 2,0 kg, initially at rest on a smooth, horizontal surface, has forces acting on it as shown in the diagram:



Under the action of the forces shown, the block will

A. remain stationary
B. accelerate to the right
C. accelerate to the left
D. accelerate upwards.

1.4 The diagram below shows a pot of weight 40 N suspended from point C by a rigid strut AC fixed to the wall at A and a light chord BC attached to the wall at B.



Which statement about the forces acting on point C is true?

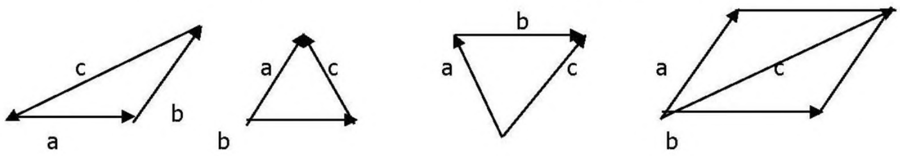
A. The vertical component of the tension in chord BC is equal to 40 N upwards.

B. The tension in chord BC must be 40 N.

C. The tension in cord BC is less than 40 N.

D. The vector sum of the three forces acting on C must be 40 N.

1.5 Which of the following vector diagrams shows "c" as the **equilibrant** of "a" and "b"?



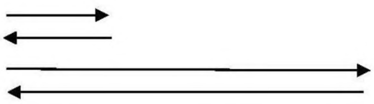
A. B. C. D.

1.6 A boy, practising his tennis, hits a ball horizontally against a wall and it rebounds horizontally with half its initial speed. The vector below represents the momentum of the ball before it collided with the wall

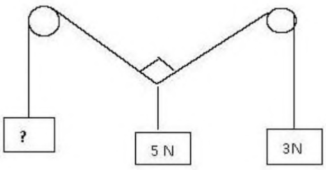
momentum of ball

The change in momentum of the ball can be represented by

A.
B.
C.
D.



1.7 Three strings are knotted together and two of them are hung over frictionless pulleys, as shown in the diagram below. Three weights are attached to the strings as shown and the angle between the strings over the pulleys is a right angle. If two of the weights exert forces of 3 N and 5 N respectively, what force will the third weight exert, if the system is in equilibrium?



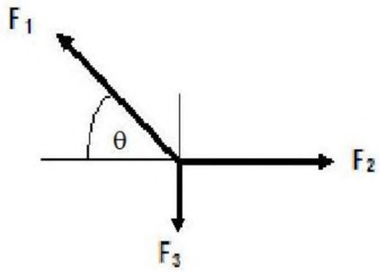
A. 4 N

B. 3 N

C. 7 N

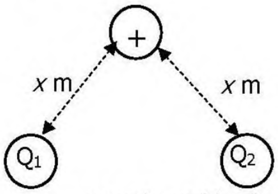
D. 8 N

1.8 A box is being dragged across a tarmac surface at constant velocity to the left using a rope. Which one of the following combinations would be appropriate labels for F_2 and F_3?



	F_2	F_3
A	$F_1.\cos\theta$	F_N
B	$F_1.\sin\theta$	F_{fric}
C	F_N	F_g
D	F_{fric}	F_g

1.9 A positive test charge is placed in the electric field of two identical positively charged objects (Q_1 and Q_2) as shown in the diagram.

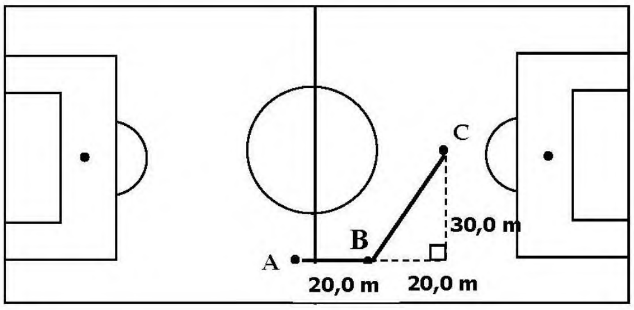


The net force experienced by the test charge will be…

A. Zero B. Upwards C. Downwards D. to the left

QUESTION 2:

In a soccer match, a player runs 20,0 m due East in 10,0 s (from position A to position B in the diagram below). He then breaks through the opposition's defence and is able to run to position C in another 10,0 s. Position C is 20,0 m East of B and 30,0 m North of B.



2.1 What is the difference between distance and displacement? Illustrate your answer with an example of each. [4]

2.2 Determine the magnitude and direction of the player's displacement from A to C. [5]

2.3 Calculate the magnitude of the player's velocity

(i) from A to B, and [3]

(ii) from B to C. [5]

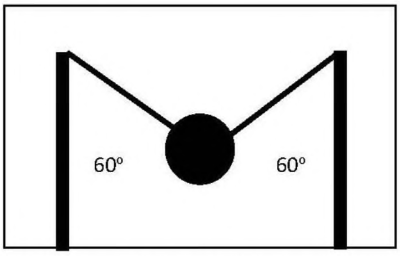
2.4 Calculate the player's average speed. [3]

2.5 Calculate the player's average velocity. [4]

[24]

QUESTION 3:

An amusement Park has a miniature "bungee" for small children. It consists of two elastic ropes fixed to two poles. The child is harnessed to the two elastic ropes.



http://www.alamy.com/stock-photo-little-girl-age-5-6-on-bungee-trampoline-concept-risk-with-copy-space-98080586.html

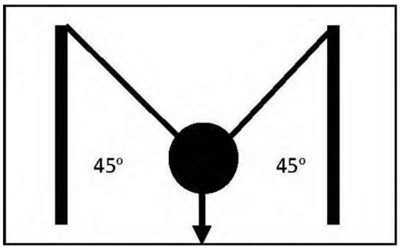
A little girl of mass 34,7 kg is hanging in the harness at rest. The rope on each side makes an angle of 60° with the vertical poles.

3.1 What is meant when an object is said to be *in equilibrium*? (2)

3.2 Draw a labelled free body diagram of the forces acting on the little girl while she is at rest in the harness. (3)

3.3 Calculate the tension in each of the elastic ropes while the girl is hanging at rest. (4)

The girl is now pulled down a distance of 2 m to just above the ground and held stationary by a force of 260 N. The ropes now make an angle of 45° with the poles.



3.4 Calculate the NEW tension in each of the elastic ropes. (4)

The downward force of 260 N is now removed and the child accelerates upward. Assume that the upward force of the two ropes remains constant while acting on the child over the first 2 m of her upward trip, after which the ropes no longer exert any force of the girl.

3.5 Write down *Newton's Second Law of Motion.* (2)

3.6 What is the net force acting on the girl as she accelerates upward over the first 2 m? (2)

3.7 Calculate the acceleration of the girl over the first 2 m. (3)

3.8 Show that the girl's velocity after accelerating upward over the first 2 m is 5,47 m.s^{-1}? (4)

3.9 Calculate the girl's change in momentum over the 2 m. (4)

3.10 Define *Impulse.* (2)

3.11 Use the concept of impulse to find the time that the girl accelerates upwards over the 2 m. (3)

3.12 How high above the ground is the girl when she comes to rest again? (5)

3.13 Draw a velocity-time graph for the motion of the girl from when she is released to when she comes to rest. Make use of all the values that you have calculated, but no further values need to be calculated. (5)

[43]

QUESTION 4:

Finger Board is a game in which you flick flat disks across a hardboard surface, they collide with other disks which then hopefully go into pockets on the corners of the board.

The disks have a mass of 10g each. A disk is flicked with a velocity of 0,5 $m.s^{-1}$ towards another disk. It hits the second, stationary disk 0,4 s later with a velocity of 0,3 $m.s^{-1}$.

4.1 Define *acceleration*. (2)

4.2 Calculate the acceleration of the disk. (3)

4.3 Draw a labelled free body diagram of the <u>horizontal force(s)</u> acting on the disk as it travels across the board. (1)

4.4 Calculate the coefficient of dynamic friction between the disk and the board. (3)

After the flicked disk has collided with the second, stationary disk, the second disk moves off at 0,2 $m.s^{-1}$ in the same direction.

4.5 State the *Principle of Conservation of Momentum*. (2)

4.6 Calculate the velocity of the first disk immediately after the collision. (4)

The board is now cleared of all disks and tilted at an angle of 30° to the horizontal. A disk is placed on the inclined surface and slides down the slope at a <u>constant velocity</u>.

4.7 Draw a labelled free body diagram of the forces acting on the disk. (3)

4.8 Calculate the magnitude of the actual force of dynamic friction between the disk and the board. (4)

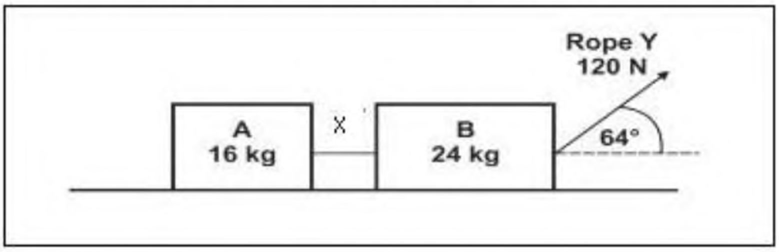
4.9 If the disk is flicked up the incline with an initial velocity, calculate the acceleration of the disk as it slides up the slope. (5)

[27]

QUESTION 5:

Two different boxes A and B of masses 16 kg and 24 kg respectively are pulled across a smooth (frictionless) surface by means of a light inextensible rope, Y, inclined at 64° to the horizontal.

The rope, Y, exerts a constant force of 120 N on box B. The box are joined by a light inextensible string, X.

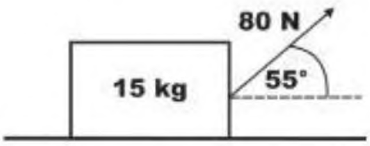


The masses of rope Y and string X are negligible compared with those of boxes A and B.

5.1 Calculate the horizontal component of the applied force. (3)

5.2 Calculate the magnitude of the acceleration of both boxes A and B. (3)

5.3 Calculate the magnitude of the tension in the string X, between boxes A and B. (3)



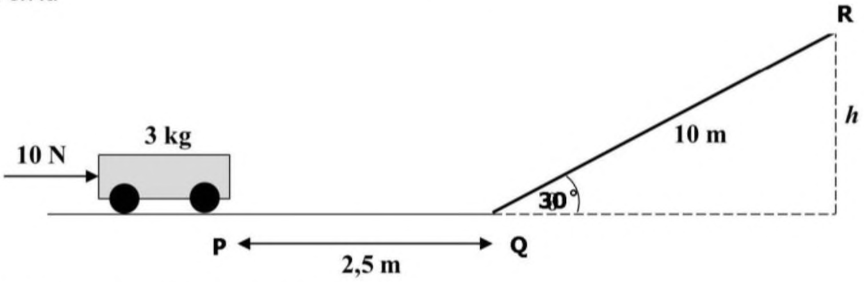
5.4 A box of mass 15 kg is at rest on a rough horizontal surface. The box is pulled by means of a light inextensible rope which exerts a force at an angle of 55° to the horizontal. The maximum force which the rope can exert before the block starts to move is 80 N. Calculate the co-efficient of static friction between the block and the surface. (6)

[15]

QUESTION 6:

A 3 kg trolley is at rest on a horizontal frictionless surface. A constant horizontal force of 10 N is applied to the trolley over a distance of 2,5 m, between points labelled **P** and **Q** as in the sketch below.

When the force is removed at point **Q**, the trolley moves a distance of 10 m up the 30° incline until it reaches the maximum height at point **R**. While the trolley moves up the incline, there is a constant frictional force of 2 N acting on it.



6.1 State the *work-energy theorem* in full. (2)

6.2 Use the work-energy theorem to calculate the speed of the trolley when it reaches point **Q**. (4)

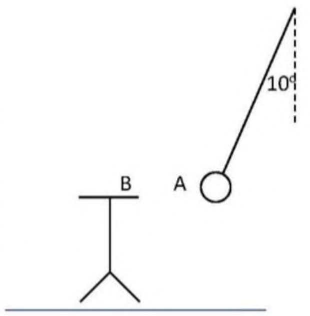
6.3 Calculate the height, h, that the trolley reaches at point **R**. (4)

6.4 Draw a labelled free body diagram of all the forces acting on the trolley as it moves up the ramp between points **Q** and **R**. (3)

6.5 What force would have to be exerted on the trolley to move it at a constant velocity up the slope? (6)

[Adapted from St Mark's 2015]

QUESTION 7:



The diagram shows a tiny metal ball **A**, of mass 1,0 g suspended by a light thread. **A** carries a large electric charge of +40 uC. A neutral gold leaf electroscope, B is moved slowly towards **A** from the left.

As they approach, it is observed that **A** *suddenly* swings to the left and comes to rest so that the thread makes an angle of 10 degrees with the vertical. At the same time, the leaves of B separate. **A** and B are stationary now and have not touched.

7.1 B is neutral, however its leaves are separate. Draw a sketch of B to show why this happens. (4)

7.2 Determine the electrostatic force experienced by **A**. (7)

7.3 Determine the strength of electric field that **A** is experiencing. (5)

7.4 Use Coulomb's Law to explain why the movement of A happens *suddenly.* (4)

[20]

APPENDIX E.3: Revision Resource on Forces, Tension and Inclines

(VERSION 4) – Solutions shown in colour

Iteration 4 – Grade 11 July 2019

PHYSICS: VECTORS
G11 Revision on Forces, tension and inclines

CONTENT FOCUS FOR THIS REVISION MODULE (from the IEB SAGs document):

Vectors

- Define a vector as *a physical quantity that has both magnitude and direction* and give examples
- Define a scalar quantity as *a physical quantity that has magnitude only* and give examples
- Define resultant vector as *the single vector which has the same effect as the original vectors acting together*
- Determine the resultant vector of any two vectors
- Determine two perpendicular components of any vector (e.g. force at an angle, weight on an inclined plane)

Newton's Laws and Application of Newton's Laws

Different Kinds of Forces: weight, normal force, frictional force, applied (push, pull) force, tension (strings or cables)

- Define weight Fg as the gravitational force the Earth exerts on any object on or near its surface
- Calculate weight using the expression Fg = mg where g is the acceleration due to gravity. Near the surface of the earth the value is approximately 9,8 $m \cdot s^{-2}$.
- Define normal force, FN, as the perpendicular force exerted by a surface on an object in contact with it
- Define frictional force due to a surface, F_f, as the force that opposes the motion of an object and acts parallel to the surface with which the object is in contact
- Explain what is meant by the maximum static friction
- Calculate the value of the maximum static frictional forces for objects at rest on horizontal and inclined planes using: $F_{s,max} = \mu_s F_N$ where μ_s is the coefficient of static friction
- Solve problems where the static frictional force is less than the maximum frictional force
- Distinguish between static and kinetic friction forces
- Calculate the kinetic frictional force using: $F_k = \mu_k F_N$ where μ_k is the coefficient of kinetic friction

Force Diagrams, Free Body Diagrams

- Draw a labelled force diagram by representing the object(s) of interest with all the forces acting on it (them) drawn in as arrows. The forces must be named (e.g. Weight, normal, force A on B, friction, air resistance)
- Draw a free-body diagram by drawing the object of interest as a dot and all the forces acting on it drawn as arrows pointing away from the dot. The forces must be named (e.g. weight, normal, force A on B, friction, air resistance)
- Resolve two-dimensional forces into parallel (x) and perpendicular (y) components (e.g. the weight of an object with respect to an inclined plane)
- Calculate the resultant or net force in the x-direction as a vector sum of all the components in the x-direction and the resultant or net force in the y-direction as a vector sum of all the components in the y-direction

Newton's First, Second and Third laws

- State Newton's first law: *An object continues in a state of rest or uniform (moving with constant) velocity unless it is acted upon by a net or resultant force*
- Define inertia as the property of an object that causes it to resist a change in its state of rest or uniform motion
- State Newton's second law: *When a net force,* F_{net}, *is applied to an object of mass, m, it accelerates in the direction of the net force. The acceleration, a, is directly proportional to the net force and inversely proportional to the mass*
- Solve problems using
  $F_{net} = ma$
- Apply Newton's laws to a variety of equilibrium and non-equilibrium problems.
  (e.g. Use Newton's second law to solve problems including an object moving on a horizontal/inclined plane (frictionless and rough), vertical motion (e.g. Rockets, hoisting masses etc.) and also two-body systems such as two masses joined by a light (negligible mass) string moving in a straight line either vertically or horizontally)

<u>Here are some reminders or the key concepts we have covered that we will need:</u>

- Newton's First Law: ***An object continues in a state of rest or uniform velocity unless acted on by an external net force.***

- When the <u>net force is zero</u>, the object can be described as being in <u>EQUILIBRIUM</u>.
- Any object that is not accelerating is in equilibrium, whether it is stationary or moving at a constant velocity.
- *If a body is in equilibrium, it does <u>not</u> necessarily mean that there are NO forces acting on it. It means that the NET FORCE IS ZERO – the forces balance each other.*

- Newton's Second Law (in terms of acceleration): ***When a net force is applied to an object, it accelerates in the direction of the net force. The acceleration is directly proportional to the <u>net force</u> and inversely proportional to the mass of the body.***

  $\mathbf{F_{net} = ma}$ **AND** $\mathbf{F_{net}}$ **= vector sum of all forces acting :** $\mathbf{F_{net} = F_1 + F_2 + F_3 + ..}$

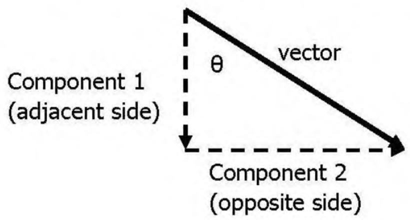
- You are finding a <u>vector</u> sum and so you must choose a positive direction and apply it.

- Always draw a free body diagram of the forces acting on the object or system that you are considering.
  - Your labels should always include <u>what is exerting the force</u>, <u>on what</u> and <u>in what direction</u>.

- The frictional force (F_F) due to a surface is the force that **<u>opposes the motion</u>** of an object.
  - The frictional force on an object <u>acts parallel to the surface</u> with which the object is in contact.
  - The actual (or minimum) frictional force is the frictional force acting on the object and can be determined using the vector sum of forces acting parallel to the surface.
  - Maximum static friction is the frictional force that must be overcome before the object will start to slide and can be determined using $F_{friction} = \mu_{s,\,max} \,.\, F_N$

<u>Perpendicular components</u> are vectors (perpendicular to one another) that have the same effect as the resultant vector.

To find components, use trigonometry:



$$\frac{\text{component 1}}{\text{vector}} = \cos\theta$$

$$\textbf{component 1 = (vector).cos}\ \boldsymbol{\theta}$$

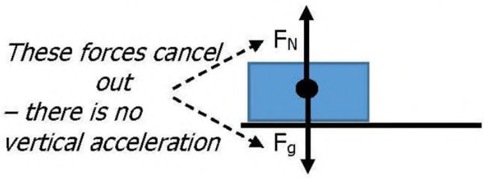
$$\frac{\text{component 2}}{\text{vector}} = \sin\theta$$

$$\textbf{component 2 = (vector).sin}\ \boldsymbol{\theta}$$

To solve a problem, identify the forces acting using a free body diagram.

Here are a number of examples of objects in equilibrium.

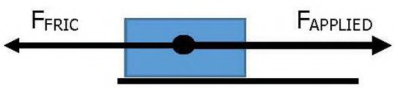
A block is resting on a horizontal surface:



$F_{NET} = F_N + F_g = 0$

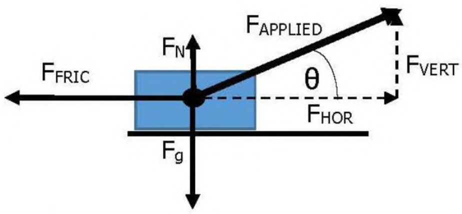
$\therefore \; F_N = - F_g$

A block being pulled (or pushed) across a rough surface at constant velocity:



$F_{NET} = F_{APP} + F_{FRIC}$

A block being pulled across a rough surface at constant velocity by a force applied at an angle:



Here you would have to find the perpendicular components of the applied force to find the F_{NET} horizontally and vertically – more about components shortly.

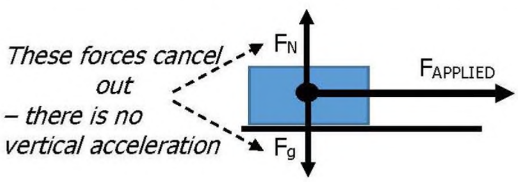
$F_{NET(HOR)} = F_{HOR} + F_{FRIC}$

$F_{NET(VERT)} = F_{VERT} + F_g + F_N$

Note that the force applied at an angle means that F_N is no longer equal in magnitude to F_g.

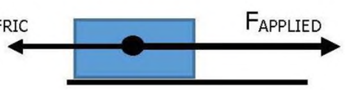
The block does not have to be in equilibrium:

A block being pulled (or pushed) across a smooth surface (when there is no frictional force):



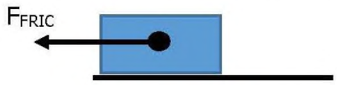
$F_{NET} = F_{APP}$

A block being pulled (or pushed) across a rough surface:



$F_{NET} = F_{APP} + F_{FRIC}$

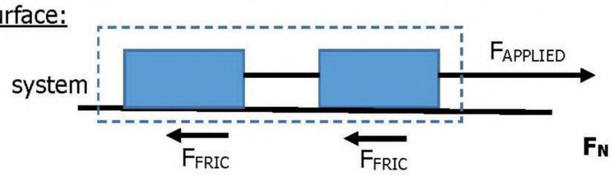
A block that was pulled (or pushed) across a rough surface, after the applied force is removed:



$\mathbf{F_{NET} = F_{FRIC}}$

This is what happens when any object skids to rest or a car brakes – the frictional force is the only horizontal force acting.

How to determine the tension in a cable between a set of blocks being pulled across a rough surface:



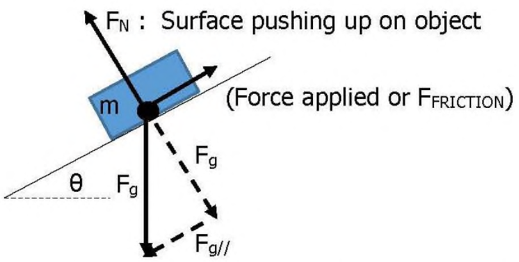
$\mathbf{F_{NET(system)} = F_{APP} + F_{FRIC(1)} + F_{FRIC(2)}}$

To find the tension between the two blocks

- Calculate the acceleration of the system: $\mathbf{a_{system} = \dfrac{F_{NET(system)}}{m_{(system)}}}$
- Consider the forces on ONE object only: $\mathbf{F_{NET(object)} = F_1 + F_2 + \ldots = (m_{object})(a_{system})}$

Inclined planes:

When a block is on an incline, a component of the weight of the block acts parallel to the incline and so needs to be considered when calculating the F_{NET}.

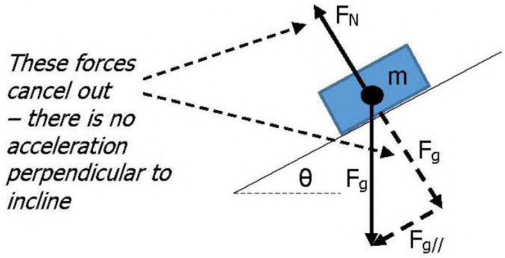


Weight is always vertically downwards, but it has perpendicular components:

- $F_{g//}$: component of weight down the slope
- $F_{g\perp}$: object pushing on surface

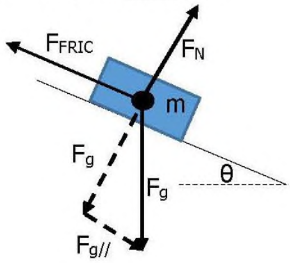
- The object is not accelerating perpendicular to the surface and so F_N and $F_{g\perp}$ will always be equal.
- When the force applied (or the frictional force) up the incline is equal to $F_{g//}$, the object will not accelerate parallel to the incline.
- You can determine the F_{NET} and therefore the acceleration of the object parallel to the incline by finding the vector sum of the forces acting parallel to the incline (just like we did in Chapter 4).

A block on a smooth incline (no friction):



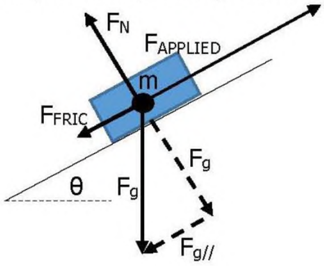
$$F_{NET} = F_{g//}$$

A block on a rough incline (no $F_{APPLIED}$):



$$F_{NET} = F_{g//} + F_{FRIC}$$

A block being pulled or pushed up a rough incline:



$$F_{NET} = F_{g//} + F_{FRIC} + F_{APP}$$

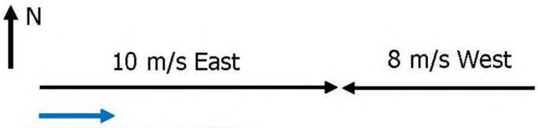
Worked Examples:

By working through these progressively more complex examples, you should begin to see patterns and be able to construct an understanding of this section.

We can find a resultant vector of any vectors, by finding the vector sum of those vectors (*this means adding the vectors, taking into account their directions – so we CHOOSE A POSITIVE DIRECTION*):

1.

2.



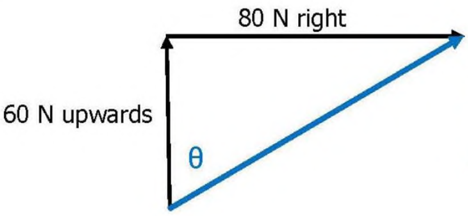
Take East as positive:

Resultant = + 10 + (- 8)

= + 2 m/s

= + 2 m/s East

3.



$\text{Resultant}^2 = 80^2 + 60^2$

Resultant = 100 N

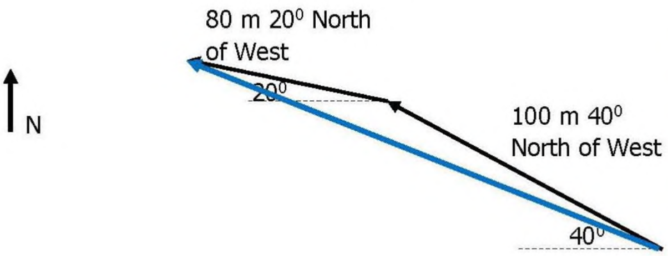
$\tan\theta = \frac{80}{60}$

$\theta = 53^0$

F_{NET} = 100 N at 53^0 to the right of the vertical

In the example below, it is easy enough to draw the resultant (an arrow from the tail of one vector to the tip of the other vector), but how do you calculate the resultant? *We could use a scale to determine the resultant, but by the end of the next section, you will be able to calculate the resultant vector using algebra.* ***Leave this out for now... we will try it again once we have revised components.***

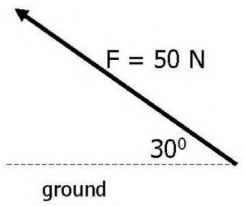
4.



We can draw this, but will need to cover the next concept before we can work it out algebraically.

We need to be able to confidently resolve **__any vector__** into its components.

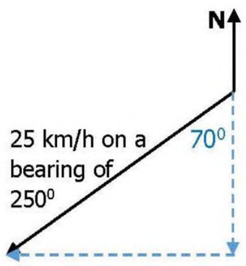
Example 1: Find the perpendicular components of a force applied at an angle:



$F_{vert} = F.\sin\theta$
$= 50.\sin 30^0$
$= 25$ N upwards

$F_{hor} = F.\cos\theta$
$= 50.\cos 30^0$
$= 43$ N to the left

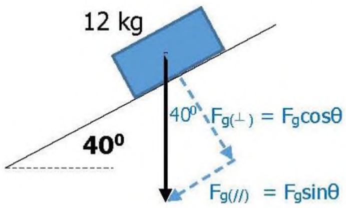
Example 2: Find the perpendicular components of a velocity at a given bearing:



$V_{SOUTH} = v.\cos\theta$
$= 25.\cos 70^0$
$= 8{,}55$ km/h South

$V_{WEST} = v.\sin\theta$
$= 25.\sin 70^0$
$= 23{,}5$ km/h West

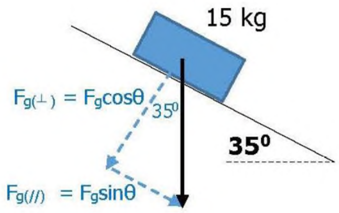
Example 3: Find the perpendicular components of the weight of an object on an incline:



$F_g = 117{,}6$ N

$F_{g(\perp)} = F_g.\cos\theta$
$= 117{,}6.\cos 40^0$
$= 90$ N $\perp$ slope

$F_{g(//)} = F_g.\sin\theta$
$= 117{,}6.\sin 40^0$
$= 75{,}6$ N // slope, down slope



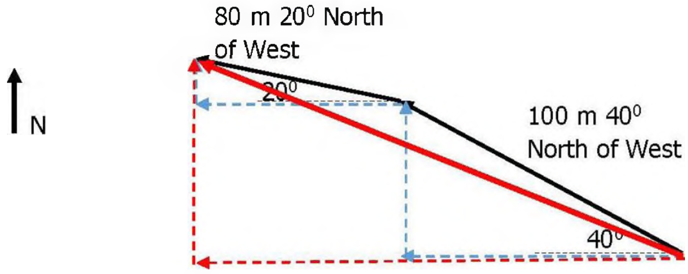
$F_g = 147$ N

$F_{g(\perp)} = F_g.\cos\theta$
$= 147.\cos 35^0$
$= 120$ N $\perp$ slope

$F_{g(//)} = F_g.\sin\theta$
$= 147.\sin 35^0$
$= 84$ N // slope, down slope

So to find the resultant vector in the example that we skipped over on page 5, we could find the perpendicular components of each vector and add the *components* of the vectors to give the *components* of the resultant:

Try it now:



S_{WEST} = 80cos20^0 + 100cos40^0

= 151,78 m West

S_{NORTH} = 80sin20^0 + 100sin40^0

= 91,64 m North

$S_{resultant} = \sqrt{(151{,}78)^2 + (91{,}64)^2}$

= 177,3 m

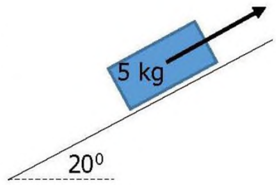
$\theta = \tan^{-1}\left(\frac{91{,}64}{151{,}78}\right) = 31{,}12^0$

s_{res} = 177,3 m bearing 301,12^0

<u>FINDING THE VECTOR SUM AND RESOLVING VECTORS INTO THEIR PERPENDICULAR COMPONENTS ARE THE KEY SKILLS IN THIS SECTION.</u>

Inclined planes examples:

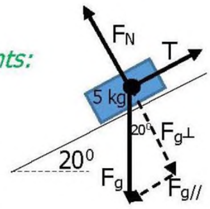
Example 1: A rope pulls the block (mass 5 kg) up the slope at a **constant velocity**. Friction between the block and incline can be ignored.



1.1 Determine the component of the weight of the block parallel to the incline.

$F_{g//} = mg.\sin\theta$
$= (5)(9{,}8)\sin 20^0$
$= 16{,}76$ N down the slope

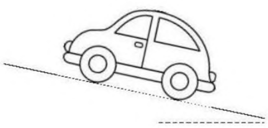
Always draw a free body diagram, showing components:



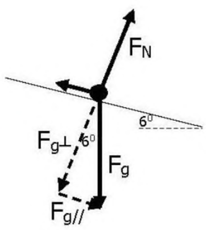
1.2 Determine the tension in the rope.

The tension in the rope = 16,76 N, as the tension in the rope must oppose the component of the block's weight parallel to the surface.

Example 2: A car (mass 1000 kg) is **parked** on a 6^0 slope. What minimum frictional force must the car experience?



Always draw a free body diagram, showing components:

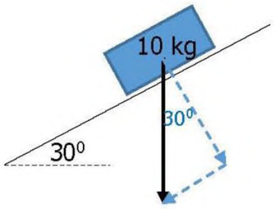


$F_{g//} = mg.\sin\theta$
$= (1000)(9{,}8)\sin 6^0$

$= 10\ 244$ N down the slope

The frictional force acting on the car is 10 244 N up the slope

Example 1: Determine the F_{fric}^{max} if μ_s^{max} = 0,4 and the mass of the block is 10 kg.

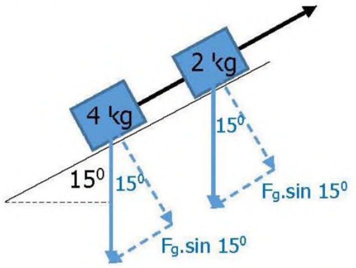


$F_{\perp} = F_g$

$F_{g(\perp)} = F_g.\cos\theta$
$= 98.\cos30^0$
$= 84{,}87$ N $\perp$ slope

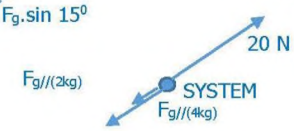
$F_{fric}^{max} = \mu_{s,}^{max}.F_N$
$= 0{,}4(84{,}87)$
= 34 N up the slope

Example 2: Determine the acceleration of the two blocks, if they are pulled up the slope with an applied force of 20 N. Friction between the blocks and incline can be ignored.

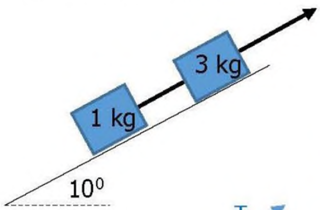


$F_{g(//)TOT} = F_{g(4)}.\sin\theta + F_{g(2)}.\sin\theta$
$= (4)(9{,}8)\sin15 + (2)(9{,}8)\sin15$
$= 10{,}15$ N $+ 5{,}07$ N $= 15{,}22$ N down the slope

$a = \dfrac{F_{NET}}{m} = \dfrac{20 + (-10{,}15) + (-5{,}07)}{6} = 0{,}8$ m/s² up the slope

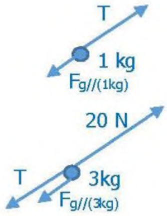


Example 3: Determine the tension in the rope between the two blocks, if they are pulled up the slope with an applied force of 20 N. Friction between the blocks and incline can be ignored.



$F_{g(//)TOT} = F_{g(1)}.\sin\theta + F_{g(3)}.\sin\theta$
$= (1)(9{,}8)\sin10 + (3)(9{,}8)\sin10$
$= 1{,}7$ N $+ 5{,}11$ N $= 6{,}81$ N down the slope

$a = \dfrac{F_{NET}}{m} = \dfrac{20 + (-1{,}7) + (-5{,}11)}{4} = 3{,}3$ m/s² up the slope

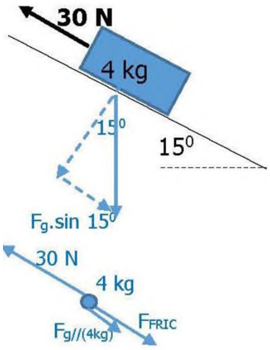


Using 1kg block: $T + F_{g//} = m_1a$
$T + (-1{,}7) = 1(3{,}3)$
$T = 5$ N up the slope on 1kg block

Using 3kg block: $T + F_{g//} + F_{APP} = m_3a$
$T + (-5{,}11) + 20 = 3(3{,}3)$
$T = -5$ N
$T = 5$ N down the slope on 3kg block

11

Example 4: The block shown is pulled up the slope with a force of 30 N. The block experiences a frictional force of 8 N. Determine the acceleration of the block.

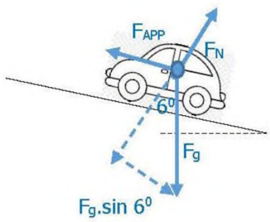


NB We only consider the forces (and components of forces) that are parallel to the inclide as F_N and $F_{g\perp}$ cancel each other out.

$$F_{g(//)TOT} = F_{APP} + F_{FRIC} + F_g.\sin\theta = ma$$
$$30\text{ N} + (-8\text{ N}) + (-(4)(9{,}8)\sin 15) = 4a$$
$$30\text{ N} + (-8\text{ N}) + (-10{,}14) = 4a$$
$$11{,}86\text{ N} = 4a$$

$$a = \frac{F_{NET}}{m} = \frac{11{,}86}{4} = 3{,}95\text{ m/s}^2 \text{ up the slope}$$

Example 5: A car (mass 1000 kg) drives **up** a 6^0 slope. The driving force applied by the engine is 1 500 N. Calculate the acceleration of the car.

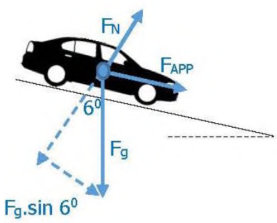


NB We only consider the forces (and components of forces) that are parallel to the incline as F_N and $F_{g\perp}$ cancel each other out.

Take up the slope as the positive direction:

$$F_{APP} + F_{g(//)} = ma$$
$$F_{APP} + F_g.\sin\theta = 1000a$$
$$1500 + (-(1\ 000)(9{,}8)\sin 6) = 1000a$$
$$1500 + (-1024) = 1000a$$
$$a = 0{,}476\text{ m/s}^2 \text{ up the slope}$$

Example 6: A car (mass 1000 kg) drives **down** a 6^0 slope. The driving force applied by the engine is 1 500 N. Calculate the acceleration of the car.



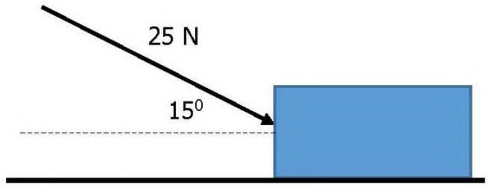
NB We only consider the forces (and components of forces) that are parallel to the incline as F_N and $F_{g\perp}$ cancel each other out.

Take down the slope as the positive direction:

$$F_{APP} + F_{g(//)} = ma$$
$$F_{APP} + F_g.\sin\theta = 1000a$$
$$1500 + (1\ 000)(9{,}8)\sin 6 = 1000a$$
$$1500 + 1024 = 1000a$$
$$a = 2{,}5\text{ m/s}^2 \text{ down the slope}$$

Forces applied at an angle:

Example 1:



1.1 Determine the normal force acting on the 10 kg box.

The block is not accelerating vertically, so $F_N + F_N + F_{VERT} = 0$

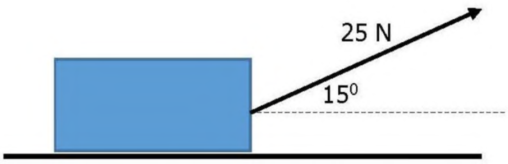
$F_{VERT} = F.\sin\theta$	$F_N + F_g + F_{VERT} = 0$ (up is positive)
$= 25.\sin 15^0$	$F_N + (10)(-9{,}8) + 6{,}47 = 0$
$= 6{,}47$ N upwards	$F_N = 98 - 6{,}47$
	$F_N = 91{,}53$ N upwards on 10 kg block

1.2 Determine the frictional force between the ground and the 10 kg box, if the box moves at a constant velocity.

If the box is moving at constant velocity, the horizontal component of the applied force must be equal in magnitude to the frictional force acting on the box (so that the vector sum of the horizontal forces is zero).

$F_{HOR} = F.\cos\theta$
$F_{HOR} = 25.\cos 15^0$
So the frictional force = 24,15 N to the left

Example 2:



2.1 Determine the normal force acting on the 10 kg box.
The block is not accelerating vertically, so $F_N + F_g + F_{VERT} = 0$

$F_{VERT} = F.\sin\theta$	$F_N + F_g + F_{VERT} = 0$ (up is positive)
$= 25.\sin 15^0$	$F_N + (10)(-9{,}8) + - 6{,}47 = 0$
$= 6{,}47$ N upwards	$F_N = 98 + 6{,}47$
	$F_N = 104{,}47$ N upwards on 10 kg block

(the normal force, which is the force of the surface upwards on the block, has increased)

2.2 The 10 kg box is just about to start sliding then this force is applied, as shown. Determine the coefficient of maximum static friction force between the ground and the 10 kg box.

F_{HOR} must equal $F_{f,s,max}$ (at the point where the box is about to slide)

$F_{HOR} = 25.\cos 15^0$	$F_{f,s,max} = \mu_{s,max}.F_N$
$= 24{,}15$ N to the right	$24{,}15 = \mu_{s,max}.104{,}47$
	$\mu_{s,max} = 0{,}23$

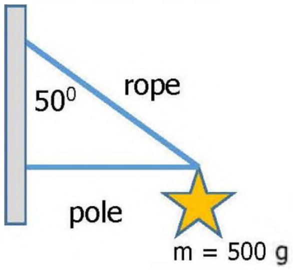
Equilibrium:

An object that is "hanging" or that is stationary, suspended by ropes or strings, is in equilibrium. This means that the forces or components of forces balance each other out.

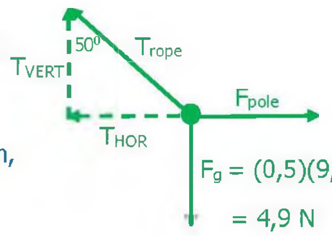
The sum of the vertical forces (or components of forces) is zero and the sum of the horizontal forces (or components of forces) is zero.

Examples:

1. A 500g decorative star is suspended by a rope from the side of a building, held away from the wall with a horizontal pole, as shown in the diagram. The rope makes an angle of 50^0 to the wall where it is tied on. Determine the tension in the rope suspending the star.



First draw a free body diagram of the forces acting on the star (or the point where the star is attached):



$F_g = (0,5)(9,8)$

$= 4,9$ N

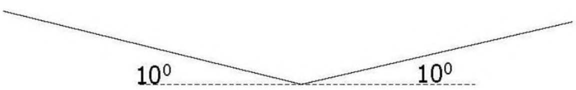
Because the star is in equilibrium,
$T_{VERT} = - F_g$

So $\dfrac{T_{VERT}}{F_{rope}} = \cos 50^0$

$F_{rope} = \dfrac{T_{VERT}}{\cos 50^0} = 7,6$ N

When there are two strings, each string supports half the weight:

2. A tight-rope walker (weight 500 N) is balancing on a piece of string. The angle that the string makes with the horizontal is 10^0. Determine the tension in the rope.



DRAW A FREE BODY DIAGRAM:

There is one rope supporting the tight rope walker, so the tension will be the same in both sections of the rope.

There are two sections, so each section supports HALF the weight of the tightrope walker (250 N).

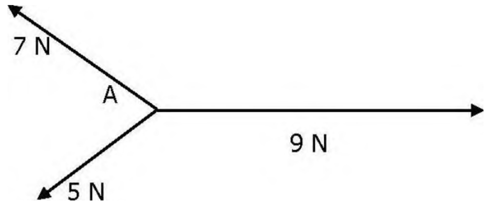
$T_{VERT} = 250$ N and $\dfrac{T_{VERT}}{F_{rope}} = \sin 10^0$ so $F_{rope} = \dfrac{T_{VERT}}{\sin 10^0} = \dfrac{250}{\sin 10^0} = 1440$ N

Equilibrant Force

The force that results in equilibrium. It is the force that "balances" the net force of the others.

Example:

Three forces keep a body in equilibrium at point A. If the force of 5N is suddenly removed, the magnitude of the **resultant** force exerted on the body at A will be



A. 7 N

B. 9 N

C. 5 N

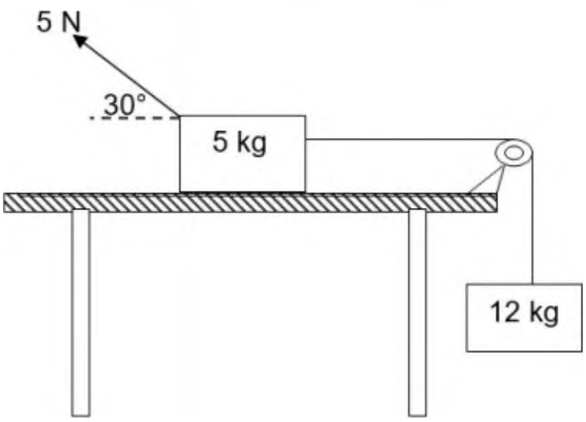
D. 2 N

If the 7 N force was removed, the magnitude of the resultant force would be 7N and if the 9 N force was removed, the magnitude of the resultant force would 9 N.

Each force is keeping the others in equilibrium – balancing the resultant of the other two forces.

A worked example

A 5 kg block, resting on a rough horizontal table, is connected to a 12 kg block by a light inextensible string that passes over a light frictionless pulley. A 5 N force is applied to the 5 kg block at 30° to the horizontal as shown in the diagram below. DoE Sept 2017

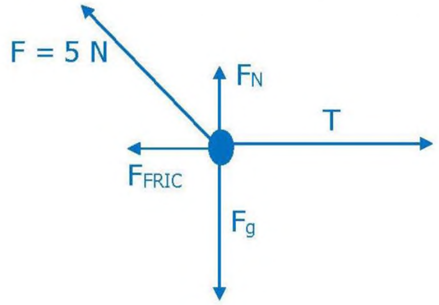


2.1 State *Newton's Second Law*. (2)

Newton's second law states that when a net force, F_{NET}, is applied to an object of mass, m, it accelerates in the direction of the net force. The acceleration, a, is directly proportional to the net force and inversely proportional to the mass of the object.

15

2.2 Draw a free-body diagram of all forces acting on the 5 kg block. (5)



2.3 The coefficient of kinetic friction (μk) between the 5 kg block and the surface is 0,2. Use Newton's Laws to calculate the magnitude of the:

2.3.1 Normal force acting on the 5 kg block (3)

$F_N + F_g + F_{VERT} = 0$ (as the block is not accelerating vertically)

$F_N + (5)(-9,8) + 5\sin 30^o = 0$

$F_N + (-49) + 2,5 = 0$

$F_N = 49 – 2,5$

$F_N = 46,5$ N upwards

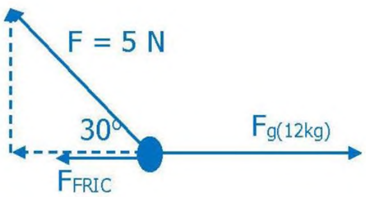
2.3.2 Kinetic frictional force acting on the 5 kg block (2)

$F_{FRIC} = \mu_K F_N$

$= 0,2(46,5)$

$= 9,3$ N to the left

2.3.3 Acceleration of the 5 kg block (4)



$F_{NET} = ma$

System: $F_{FRIC} + F_{HOR} + F_{g(12kg)} = ma$

$-9,3 + (-5\cos 30^o) + 12(9,8) = (12 + 5)a$

$- 9,3 + (- 4,33) + 117,6 = 17\ a$

$\frac{103,97}{17} = a$

$a = 6,11\ m/s^2$ to the right / clockwise

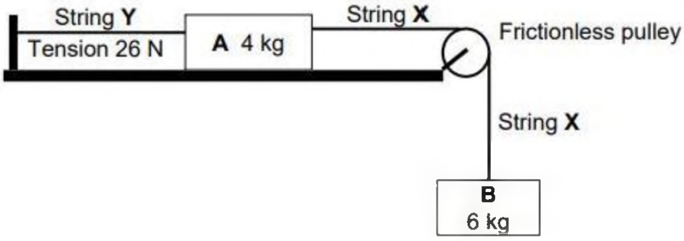
[16]

16

Revision Worksheet

Question 1:

Block A (mass 4 kg) and Block B (mass 6kg) are connected via a light, inextensible string, X, over a frictionless pulley. Block A, which is at rest on a rough horizontal surface, is tied via a light inextensible string, Y, to a fixed post as shown in the diagram. The tension in string Y is 26 N.



Block A as shown in the diagram is only just at rest and is on the limit of sliding to the RIGHT.

1.1 State *Newton's first law*. (2)

1.2 State the magnitude of the net force acting on Block B. (1)

1.3 Calculate the magnitude of the tension in string X. (2)

1.4 Draw a labelled force diagram to represent the horizontal forces acting on Block A. (4)

1.5 Calculate the magnitude of the maximum force of static friction acting on block A. (2)

1.6 Calculate the co-efficient of static friction between Block A and the surface. (3)

String Y is cut and the system starts accelerating. The tension in string X is now 40,2 N.

1.7 State *Newton's second law.* (2)

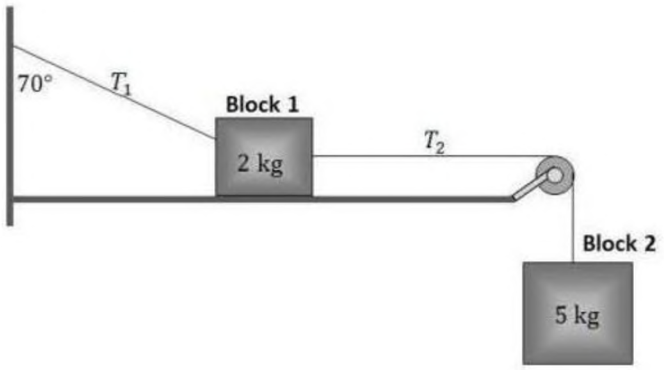
1.8 Calculate the magnitude of the acceleration of the system. (4)

1.9 Calculate the magnitude of the frictional force acting on Block A while it is accelerating. (4)

From Kearsney College Trial Examination 2017 **[24]**

Question 2:

Two blocks of different mass are attached to each other via a light inextensible string which is placed over a massless and frictionless pulley. Block 1 (mass 2 kg) is placed on a smooth surface and attached to the wall by a second string which makes an angle of 70° to the vertical as shown in the diagram below. Block 2 (mass 5 kg) is left to hang freely. The entire system is in static equilibrium and all forms of friction can be ignored.



2.1 Draw a labelled free-body diagram to represent the forces acting on Block 1 (mass 2 kg). (4)

2.2 Explain what is meant by static equilibrium. (2)

2.3 Determine the magnitude of T2. (2)

2.4 Determine the magnitude of T1. (3)

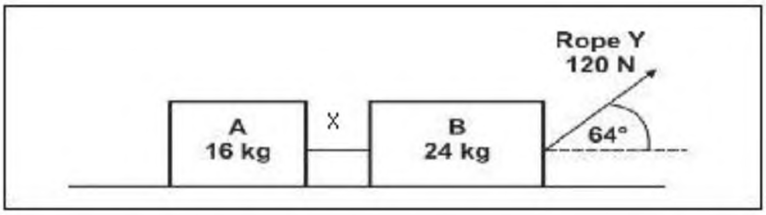
2.5 Determine the magnitude of the normal force exerted on Block 1. (3)

[14]

Question 3:

Two different boxes A and B of masses 16 kg and 24 kg respectively are pulled across a smooth (frictionless) surface by means of a light inextensible rope, Y, inclined at 64° to the horizontal.

The rope, Y, exerts a constant force of 120 N on box B. The box are joined by a light inextensible string, X.



The masses of rope Y and string X are negligible compared with those of boxes A and B.

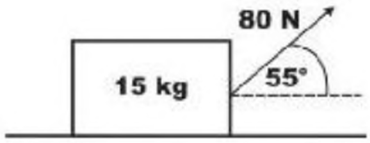
3.1 Calculate the horizontal component of the applied force. (3)

19

3.2 Calculate the magnitude of the acceleration of both boxes A and B. (3)

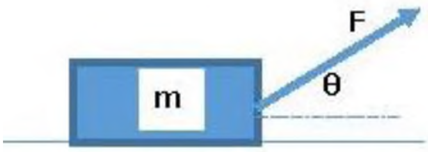
3.3 Calculate the magnitude of the tension in the string X, between boxes A and B. (3)

3.4 A box of mass 15 kg is at rest on a rough horizontal surface. The box is pulled by means of a light inextensible rope which exerts a force at an angle of 55° to the horizontal. The maximum force which the rope can exert before the block starts to move is 80 N. Calculate the co-efficient of static friction between the block and the surface. (6)



This is a typical Grade 12 question involving simultaneous equations, but actually nothing new. Try it!

A block with mass **m** is being pulled along a rough surface at a **constant velocity** with force **F**, applied at an angle to the ground as shown. Determine μ.



20

APPENDIX E.4: Revision worksheet solutions (VERSION 4)
Iteration 4 – Grade 11 July 2019

Solutions to Revision Worksheet

(Revision of Forces in Equilibrium handout)

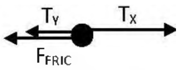
Question 1:

1.1 Newton's first law states that an object continues in a state of rest or uniform velocity unless it is acted upon by a net force.

1.2 Zero

1.3 $T_X = m_B g$
$= 6 \times 9,8$
$= 58,8$ N

1.4



1.5 $T_Y = T_X + F_{FRIC}$
$26 = 58,8 + F_{FRIC}$
$F_{FRIC} = 32,8$ N

1.6 $F_{FRIC} = \mu . F_N$

$32,8 = \mu.(4 \times 9,8)$
$\mu = 0,84$

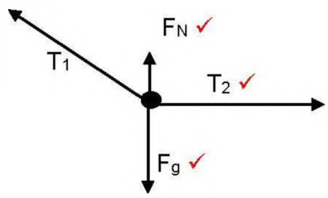
1.7 Newton's second law states that when a net force, F_{NET}, is applied to an object of mass, m, it accelerates in the direction of the net force. The acceleration, a, is directly proportional to the net force and inversely proportional to the mass of the object.

1.8 Isolate B:
$F_{NET} = ma$
$6 \times 9,8 - 40,2 = 6a$
$58,8 - 40,2 = 6a$
$a = 3,1$ m/s^2

1.9 Isolate A:
$F_{NET} = ma$
$40,2 - F_f = 4 \times 3,1$
$F_f = 27,8$ N

(or use whole system):
$F_{NET} = ma$
$6 \times 9,8 - F_f = (4 + 6)(3,1)$
$F_f = 27,8$ N

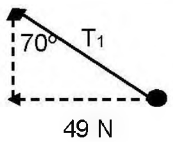
2.1



2.2 Static equilibrium is when the vector sum of the forces acting on an object is zero and the object is not moving.

2.3 T_2 = the weight of the hanging block
$= (5)(9,8) = 49$ N

2.4



$\frac{49}{T_1} = \sin 70^0$

$T_1 = 52$ N

2.5 $F_N + F_g + T_{1(vert)} = 0$

$F_N + (2)(-9.8) + 52\cos 70^0 = 0$

$F_N = 19,6 - 17,8$

$F_N = 1,77$ N upwards

Question 3:

3.1 $F_{HOR} = 120 \cos 64^0$ ✓
$= 52{,}6$ N ✓ (to the right) (2)

3.2 $a = \frac{F_{NET}}{m} = \frac{52{,}6}{40}$ ✓ ✓ $= 1{,}32 \text{ m.s}^{-2}$ ✓ (3)

3.3 $T = F_{NET(A)} = m_{(A)}a = (16)(1{,}32)$ ✓✓
$= 21{,}04$ N ✓
(forwards on A)

OR $T + F_{HOR} = m_{(B)}a$
$T + (52{,}6)$ ✓ $= (24)(1{,}32)$ ✓
$T = -21{,}04$ N
$= 21{,}04$ N✓ (backwards on B)
(3)

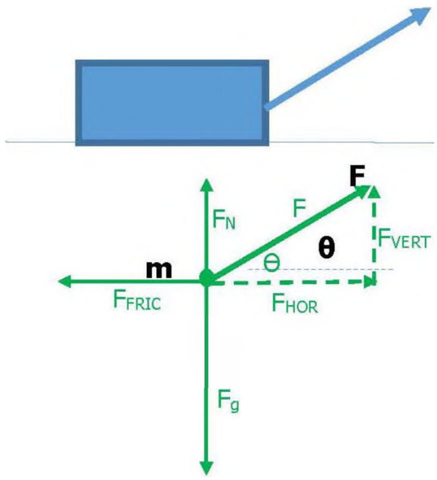
3.4 $F_{FRIC} = \mu_{s,max}F_N$

$F_{FRIC} = F_{HOR} = F.\cos\theta = 80.\cos 55^0$ ✓
$= 45{,}89$ N ✓

$F_N + F_g + F_{VERT} = 0$ Take up as +ve:
$F_N + (m)(g) + F.\sin\theta = 0$
$F_N + (15)(-9{,}8) + 80.\sin 55^0$ ✓ $= 0$
$F_N = 147 - 65{,}53$
$= 81{,}47$ N ✓

$45{,}89 = \mu_{s,max}\,(81{,}47)$
$\mu_{s,max} = \frac{45{,}89}{81{,}47}$ ✓

$= 0{,}56$ ✓ (6)



Constant velocity, so in equilibrium:
No F_{NET} in the horizontal or vertical directions

$F_{VERT} = F.\sin\theta$ $F_{HOR} = F.\cos\theta$

Considering vertical forces:
(Take up as the positive direction)

$F_N + F_{VERT} + F_g = 0$
$F_N + F.\sin\theta + (-mg) = 0$
So $F_N = mg - F.\sin\theta$

Considering horizontal forces:

$F_{HOR} = F_{FRIC}$
$F.\cos\theta = \mu.F_N$
$F.\cos\theta = \mu(mg - F.\sin\theta)$

$$\mu = \frac{F.\cos\theta}{mg - F.\sin\theta}$$

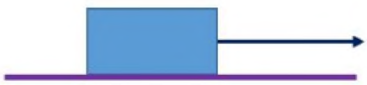
APPENDIX F.1: Pre-test for understanding of Newton's second law (NL2) and inclines

Pre-test for understanding of NL2 and inclines

These questions are intended to assess the revision tool and not you or your understanding of physics. Please answer them as best you can, but no revision is required before answering them.

Please tick the answer that you think best completes each statement.

1. A box is being pulled along a rough horizontal surface using a rope, as shown in the diagram alongside. If the frictional force is equal to the force that is applied by the rope, the box will

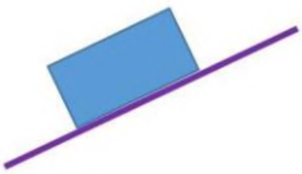


□ stop moving
□ accelerate forwards
□ slow down
□ keep moving at a constant speed.

2. A box is being pulled along a rough horizontal surface using a rope at an angle to the horizontal, as shown in the diagram alongside. If all other conditions remain the same as in question 1, the normal force acting on the box will be

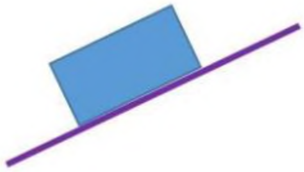
□ greater than the normal force acting on the box in question 1
□ less than the normal force acting on the box in question 1
□ the same as the normal force acting on the box in question 1
□ equal to the weight of the box in question 1

3. When a box is resting on an inclined surface, as shown alongside, the normal force is equal to the



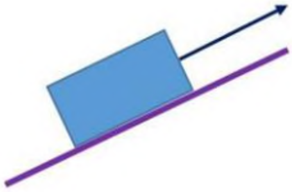
□ weight of the box
□ frictional force acting on the box
□ parallel component of the weight
□ perpendicular component of the weight

4. When a box is resting on an inclined surface, as shown alongside, the force that must be applied up the slope to keep it stationary is equal to the



□ weight of the box
□ frictional force acting on the box
□ parallel component of the weight
□ perpendicular component of the weight

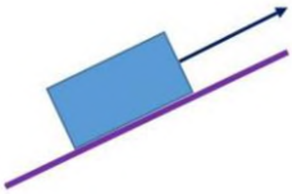
5. A box is being pulled up a rough slope by a rope. The net force will be the vector sum of



□ weight + frictional force + applied force
□ frictional force + applied force
□ perpendicular component of weight + frictional force + applied force + normal force
□ parallel component of weight + frictional force + applied force

APPENDIX F.2: Alternative Question 5 for Iteration 3 on Pre-test for understanding of Newton's second law (NL2) and inclines

5. A box is being pulled up a rough slope by a rope. The force that the rope must apply up the slope to pull the box at constant velocity is equal to



□ frictional force
□ weight + frictional force
□ frictional force + parallel component of weight
□ perpendicular component of weight + frictional force + normal force

APPENDIX F.3: Post-test for understanding of Newton's second law (NL2) and inclines

Post-test for understanding of NL2 and inclines

Remember that all these examples can be solved using the principles of finding a vector sum and resolving vectors into their components.

These questions are intended to assess my lesson and not you. Please answer them as best you can, but no additional revision is required before answering them.

Please tick the answer that you think best completes each statement.

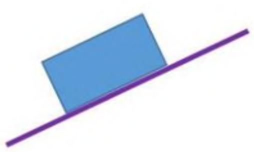
1. A box is being pulled along a rough horizontal surface using a rope, as shown in the diagram alongside. If the frictional force is equal to the force that is applied by the rope, the box will

   □ keep moving at a constant speed
   □ accelerate forwards
   □ slow down
   □ stop moving

2. A box is being pulled along a rough horizontal surface using a rope at an angle to the horizontal, as shown in the diagram alongside. If all other conditions remain the same as in question 1, the normal force acting on the box will be

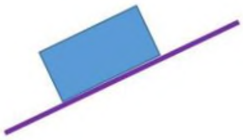
   □ equal to the weight of the box in question 1
   □ the same as the normal force acting on the box in question 1
   □ less than the normal force acting on the box in question 1
   □ greater than the normal force acting on the box in question 1

3. When a box is resting on an inclined surface, as shown alongside, the normal force is equal to the



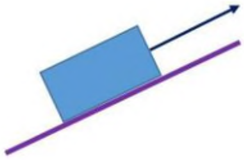
   □ weight of the box
   □ parallel component of the weight
   □ perpendicular component of the weight
   □ frictional force acting on the box

4. When a box is resting on an inclined surface, as shown alongside, the force that must be applied up the slope to keep it stationary is equal to the



- □ weight of the box
- □ frictional force acting on the box
- □ parallel component of the weight
- □ perpendicular component of the weight

5. A box is being pulled up a rough slope by a rope. The net force will be the vector sum of



- □ weight + frictional force + applied force
- □ frictional force + applied force
- □ perpendicular component of weight + frictional force + applied force + normal force
- □ parallel component of weight + frictional force + applied force

APPENDIX F.4: Evaluation Form (in Google Forms)

An evaluation of the revision material on forces at an angle and inclines

This quiz hopes to test your understanding of NL2 and inclines to be answered after working through the handout that you were given.

Remember that all these examples can be solved using the principles of finding a vector sum and resolving vectors into their components.

These questions are intended to assess the handout and not you. Please answer them as best you can, but no additional revision is required before answering them. Please be as honest as possible and don't change your answers after looking at the memo.

The purpose of this form to help me improve the Revision Handout on Forces. You can tick more than one option where there are multiple options.

* Required

1. **Email address** *

2. **Your name (optional - but it would help me to see who has made use of this resource)**

3. **A box is being pulled along a rough horizontal surface using a rope, as shown in the diagram below. If the frictional force is equal to the force that is applied by the rope, the box will** *

Mark only one oval.

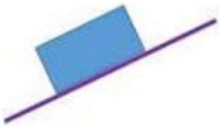
- ◯ accelerate forwards
- ◯ slow down
- ◯ stop moving
- ◯ keep moving at a constant speed.

4. **A box is being pulled along a rough horizontal surface using a rope at an angle to the horizontal, as shown in the diagram below. If all other conditions remain the same as in question 1, the normal force acting on the box will be** *

Mark only one oval.

- [ ] the same as the normal force acting on the box in question 1
- [ ] equal to the weight of the box in question 1
- [ ] less than the normal force acting on the box in question 1
- [ ] greater than the normal force acting on the box in question 1

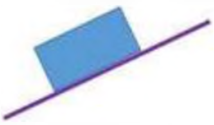
5. **When a box is resting on an inclined surface, as shown below, the normal force is equal to the** *



Mark only one oval.

- [ ] weight of the box
- [ ] frictional force acting on the box
- [ ] parallel component of the weight
- [ ] perpendicular component of the weight

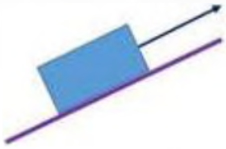
6. **When a box is resting on an inclined surface, as shown below, the force that must be applied up the slope to keep it stationary is equal to the** *



Mark only one oval.

- [ ] perpendicular component of the weight
- [ ] parallel component of the weight
- [ ] frictional force acting on the box
- [ ] weight of the box

7. **A box is being pulled up a rough slope by a rope. The force that the rope must apply up the slope to pull the box at constant velocity is equal to** *



Mark only one oval.

- ◯ frictional force
- ◯ weight + frictional force
- ◯ frictional force + parallel component of weight
- ◯ perpendicular component of weight + frictional force + normal force

8. **So far I have prepared for the Physics exam by (you can choose multiple options)** *

Check all that apply.

- [ ] reading through my notes
- [ ] learning my definitions
- [ ] practicing additional past exam questions
- [ ] attending Physics Support
- [ ] watching online videos
- [ ] working with a friend
- [ ] seeing a tutor
- [ ] I have yet to start preparing

9. **Did you work through the revision handout that you were given on forces, tension and inclines?** *

Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Part of it

10. **To what extent did you complete it? Tick the parts that you used:**

Check all that apply.

- [ ] Read notes / reminders (pages 3 - 6, 10, 13-14)
- [ ] Worked through the examples (pages 7 - 8, 11 - 12, 15 - 16)
- [ ] Worked through the whole booklet

11. **Did you complete the Revision Worksheet in the handout?**

Mark only one oval.

	1	2	3	
1 question only	◯	◯	◯	All 3 numbered questions

12. **Did you get the answers right?**
Mark only one oval.

	1	2	3	4	5	
None at all	◯	◯	◯	◯	◯	All correct

13. **I can answer questions involving objects in equilibrium**
Mark only one oval.

	1	2	3	4	5	
Very confidently	◯	◯	◯	◯	◯	Not at all confidently

14. **Did you feel that using this handout improved your understanding of this section?** *
Mark only one oval.

◯ A lot
◯ A little
◯ Not at all
◯ It confused me further

15. **If you feel that it did improve your understanding, please try to explain WHY you think it did.**

16. **If the handout confused you, please try to explain WHY you think it did.**

17. **Please provide feedback below to give me an idea of whether this was useful. I found this resource**
Mark only one oval.

	1	2	3	4	5	
Very helpful	◯	◯	◯	◯	◯	Confusing

18. **After reading through this resource,**
Mark only one oval.

- ◯ I feel confident about these concepts
- ◯ I understand these concepts better than I did before
- ◯ I understand some of the concepts better than I did before
- ◯ I still don't understand the concepts well (if this is the case, please answer the last question)

19. **Did you watch any of the videos posted?** *
Mark only one oval.

- ◯ Yes
- ◯ No

20. **If you watched the videos, please specify which ones you found helpful**
Check all that apply.

- ☐ Video 1 (basics - vector sum)
- ☐ Video 2 (basics - perpendicular components)
- ☐ Video 3 (basics - normal force)
- ☐ Video 4 (basics - suspended object in equilibrium, not on a surface)
- ☐ Video 5 (basics - inclines)
- ☐ The worked examples from the worksheet given out before the test

21. **Were the videos at all helpful?**
Mark only one oval.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Extremely helpful

22. **If you found the videos helpful, can you explain why?**

23. **If they were not helpful, can you explain why?**

24. **If this process helped your understanding, tick the reasons why you think it helped**
Mark only one oval.

- ◯ I missed some lessons and so had gaps in my understanding
- ◯ There were some concepts that I just didn't get the first time round
- ◯ I needed to hear the concepts explained again
- ◯ I needed to spend more time on the concepts - now that I have spent time, they make sense

25. **How long did you spend on this handout?**
Mark only one oval.

- ◯ no time at all
- ◯ less than half an hour
- ◯ About an hour
- ◯ 1 - 2 hours
- ◯ 2 - 3 hours
- ◯ More than 3 hours

26. **Please suggest any improvements that you think could be made to the handout.**

27. **Please suggest any improvements that you think could be made to the videos.**

28. **If you need more help, please give your name and list any questions that you still have, so that I can help you further or come to Physics Support with these questions.**

APPENDIX F.5: Example of feedback provided

× A box is being pulled along a rough horizontal surface using a rope, as shown in the diagram below. If the frictional force is equal to the force that is applied by the rope, the box will * 0 / 0

- ○ accelerate forwards
- ○ slow down
- ◉ stop moving ×
- ○ keep moving at a constant speed.

Correct answer

◉ keep moving at a constant speed.

Feedback

The box is in equilibrium because the horizontal forces acting on it are equal, but in opposite directions. This means that the box will experience no net force and it will not accelerate, so its velocity will not change. It will continue moving at CONSTANT VELOCITY.

× A box is being pulled along a rough horizontal surface using a rope at an angle to the horizontal, as shown in the diagram below. If all other conditions remain the same as in question 1, the normal force acting on the box will be * 0 / 0

- ◉ the same as the normal force acting on the box in question 1 ×
- ○ equal to the weight of the box in question 1
- ○ less than the normal force acting on the box in question 1
- ○ greater than the normal force acting on the box in question 1

Correct answer

◉ less than the normal force acting on the box in question 1

Feedback

The box will not accelerate up or down and so the vertical forces must add up to zero. Because the force by the rope is being applied at an angle, it will have an upward vertical component, which reduces the normal force. The normal force + the vertical component of the tension in the rope must equal the weight of the box to maintain equilibrium.

✕ When a box is resting on an inclined surface, as shown below, the normal force is equal to the * 0 / 0

◉ weight of the box ✕

○ frictional force acting on the box

○ parallel component of the weight

○ perpendicular component of the weight

Correct answer

◉ perpendicular component of the weight

Feedback

The box will not accelerate up off the incline (perpendicular to the incline) or into the incline, so the forces acting perpendicular to the incline must add up to zero. This means that the normal force is equal to the component of the weight that is perpendicular to the surface.

✕ When a box is resting on an inclined surface, as shown below, the force that must be applied up the slope to keep it stationary is equal to the * 0 / 0

- perpendicular component of the weight
- parallel component of the weight
- frictional force acting on the box ✕
- weight of the box

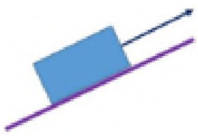
Correct answer

- parallel component of the weight

Feedback

If there was no applied force and no friction acting on this box, it would slide down the slope as a result of the parallel component of the weight. To prevent this, a force must be applied up the slope which is equal to this parallel component of the weight.

✕ A box is being pulled up a rough slope by a rope. The force that the rope must apply up the slope to pull the box at constant velocity is equal to * 0 / 0



- frictional force
- weight + frictional force ✕
- frictional force + parallel component of weight
- perpendicular component of weight + frictional force + normal force

Correct answer

◉ frictional force + parallel component of weight

Feedback

The frictional force and the parallel component of the weight are acting down the slope, parallel to the surface. So to maintain equilibrium and pull the box up the slope at constant velocity, the applied force needs to be equal to the sum of these two forces.

APPENDIX F.6: Grade 12 Follow-up question – August 2019

To conclude Iteration 3 (distributed via Google Forms)

In my preparation for my Physics exam (either in class or on my own)... *

- ○ I did NOT use the handout at all.
- ○ I looked at the worked examples in the handout, but did not do the worksheet.
- ○ I worked through the handout thoroughly.

APPENDIX F.7: Grade 11 Follow-up question – August 2019

To conclude Iteration 4 (distributed via Google Forms)

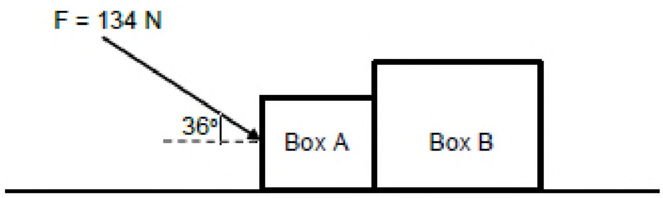
In my preparation for my Physics exam (either in class or on my own)... *

- ○ I did NOT use the handout at all.
- ○ I looked at the worked examples in the handout, but did not do any of the calculations.
- ○ I did part of the handout.
- ○ I worked through most of the handout.
- ○ I worked through the handout thoroughly.

Appendix G: Question 4 from 2018 IEB NSC Examination

QUESTION 4 AN ATHLETE IN TRAINING

An athlete trains by pushing a heavy box A of mass 23 kg, which is in contact with an even heavier box B of mass 31 kg, across the rough surface of a field as shown in the diagram below. The athlete exerts a force F = 134 N at an angle of 36° to the horizontal on box A and each box experiences a frictional force of 45 N. The boxes accelerate horizontally.



4.1 Draw a labelled free-body diagram for box A. (5)

4.2 Draw a labelled free-body diagram for box B. (4)

4.3 State *Newton's second law*. (2)

4.4 Use Newton's second law to write the equation $F_{net} = ma$ in terms of all the horizontal forces acting on **box A**. (4)

4.5 State *Newton's third law*. (2)

4.6 Calculate the force that box B exerts on box A. (3)

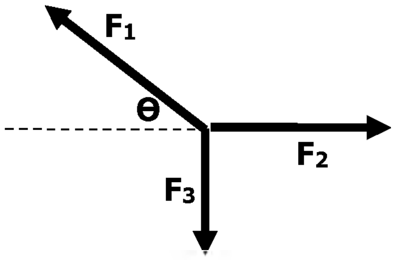
4.7 Define *frictional force due to a surface*. (2)

Box A and box B are made of identical material, yet each box experiences the same frictional force.

4.8 Use a suitable equation to help you explain why box A experiences the same magnitude frictional force even though box A has a smaller mass than box B. (3)

[25]

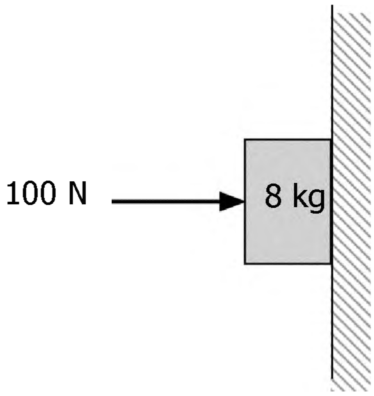
1.3 Three forces F_1, F_2 and F_3 acting at the same point, as indicated in the diagram, are in **equilibrium**. F_1 forms an angle θ to the horizontal.



The magnitude of the **horizontal** component of F_1 equals,

A. 0
B. F_2
C. F_3
D. $F_2 + F_3$

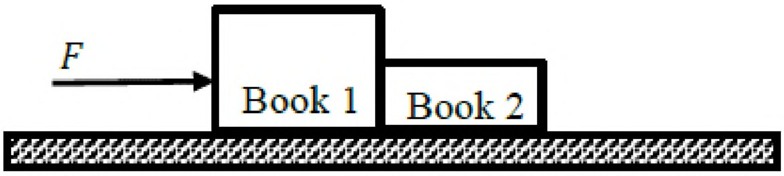
1.4 A block with a mass of 8 kg is pushed into a wall with a horizontal force of 100 N as shown in the diagram below. The maximum coefficient of static friction between the wall and the block is 0,8.



Which of the following describes the motion of the block?

A. It accelerates down the wall
B. It accelerates up the wall
C. It travels down the wall at a constant velocity
D. It remains stationary against the wall

1.5 Olivia pushes two books on a frictionless surface with a force F as shown in the diagram.

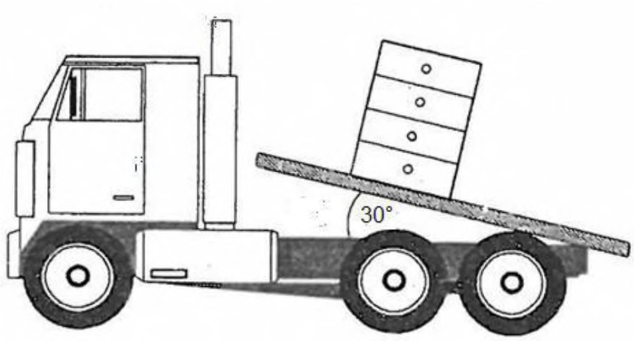


The force that Book 1 exerts on Book 2 is X. The force that Book 2 exerts on Book 1 is Y. The magnitude of force X compared to force Y is:

A $X = Y$
B $X > Y$
C $X < Y$
D Depends on the acceleration of the system.

QUESTION 4 NEWTON'S LAWS AND FRICTION

A wooden cabinet of 60 kg rests on the back of a tip-up truck. The back tilts slowly, until it makes an angle of 30° with the horizontal at which point **the cabinet is just about to move**.



4.1 State, in words, *Newton's first law of motion*. (2)

4.2 Draw a fully labelled free-body diagram of all the forces acting on the cabinet. (3)

4.3 Calculate the frictional force acting on the cabinet when the back tilts at 30°. (4)

4.4 Calculate the magnitude of the normal force that the truck exerts on the cabinet. (3)

4.5 Calculate the coefficient of static friction. (3)

4.6 The angle of 30° is now increased. How will this affect the frictional force acting on the cabinet? Give a reason for your answer. (2)

When the angle reaches 35^0 the cabinet can be seen accelerating down the tilted back of the pick-up truck. Assume the friction force acting on the wooden cabinet is now 270 N.

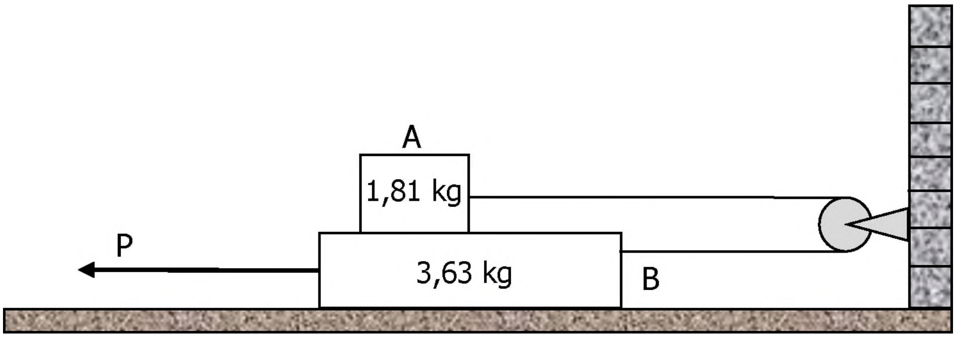
4.7 Calculate the magnitude of the acceleration of the cabinet. (5)

Hilton College Exam 2018

22 marks

QUESTION 5 PULLEYS AND FRICTION

Block A in the diagram below has a mass of 1,81 kg and block B has a mass of 3,63 kg. The coefficient of static friction between all the surfaces is 0,25. Blocks A and B are connected by a light flexible cord passing around a small frictionless pulley that is fastened to a wall. The cord will not stretch when it is pulled at its ends.



The magnitude of the applied force P is such that the block B is just about to move.

5.1 Define a *frictional force due to a surface*. (2)

5.2 Draw separate free-body diagrams for the two blocks. Label the force diagrams clearly using abbreviated labels. (No full labels required.) (5)

5.3 The horizontal forces acting on each of the two blocks are balanced. Explain what is meant by saying the 'forces are balanced'. (1)

5.4 Calculate the frictional force acting on block A. (4)

5.5 What is the magnitude of the tension in the cord connecting blocks A and B? Justify your answer. (2)

5.6 Calculate the magnitude of the frictional force acting on block B due to the surface on which it rests. (3)

5.7 Find the magnitude of the force P. (3)

Heronbridge College Exam 2018

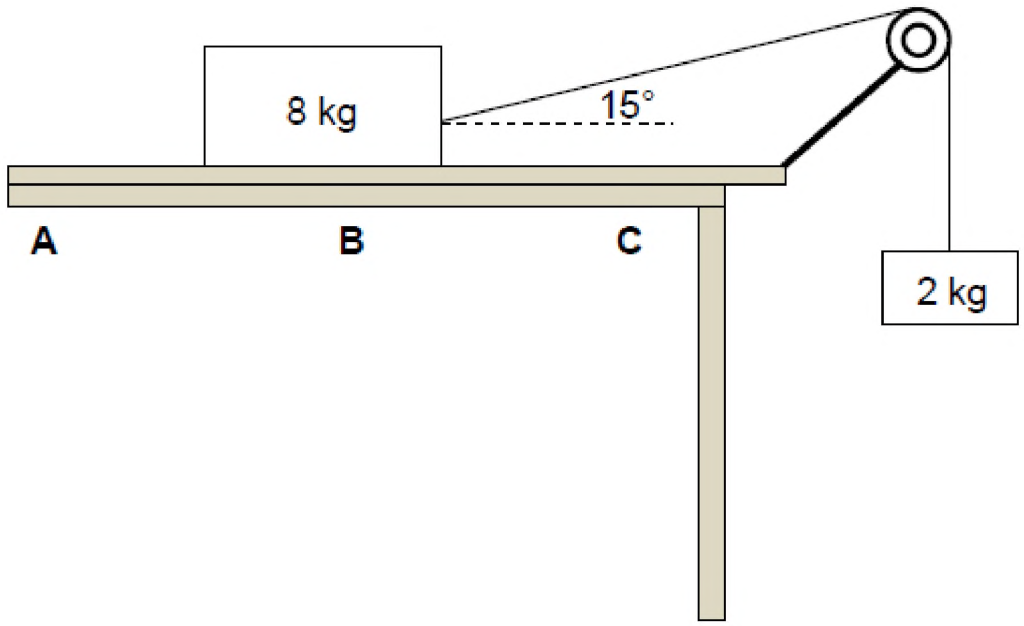
20 marks

APPENDIX I: Grade 12 Examination August 2019

QUESTION 3 NEWTON'S LAWS

(Adapted from NSC Nov 2018)

A block, of mass 8 kg, is placed on a rough horizontal surface. The 8 kg block, which is connected to a 2 kg block by means of a light inextensible string passing over a light frictionless pulley, starts sliding from point A, as shown below.



3.1 State *Newton's second law.* (2)

3.2 When the block reaches point B, the angle between the string and the horizontal is 15^{O} and the acceleration of the system is 1,32 $m.s^{-2}$.

3.2.1 Draw a labelled free-body diagram for the 8 kg block at point B. (4)

3.2.2 Determine the magnitude of the tension in the string. (3)

3.2.3 Calculate the kinetic (dynamic) frictional force between the 8 kg block and the horizontal surface. (4)

3.3 As the 8 kg block moves from B to C, the kinetic frictional force between the 8 kg block and the horizontal surface is not constant. Explain why the frictional force changes between B and C. (3)

3.4 The 2 kg mass is replaced with a heavier mass. How, if at all, would this change affect the frictional force acting on the 8 kg mass at point B? Briefly explain your answer. (3)

To raise a significantly heavier mass to this table, a small motor is set up. It can raise a 10 kg load at a constant speed of 0,4 m/s.

3.5 Determine the power output of the motor as raises the load. (3)

3.6 If the motor cable snaps when the load is 1,2 m above the ground, calculate the velocity with which the load will hit the ground. (4)

[26]

APPENDIX J: Grade 11 Test July 2019

1.1 A box with a mass of 10 kg is resting on a slope that is inclined at 8° to the ground. The normal force is equal to

A. 98 N B. 13,6 N C. 97 N D. 13,8 N (2)

QUESTION 3

Image: 8 year old Sky Brown preparing for a skate-boarding competition. https://qz.com/784089/sky-brown-an-8-year-old-japanese-skateboarder-became-the-youngest-

A young girl slides down a stair rail, which is at an angle of 15° to the ground. The mass of the girl and her skateboard is 40 kg. *[Treat the girl and her skateboard as one object.]*

The girl (on her skateboard) slides down the rail at a constant velocity.

3.1 Draw a free-body diagram of the forces acting on the girl-skateboard system. (3)

3.2 Calculate the component of the girl-skateboard system's weight that is acting parallel to the stair rail. (4)

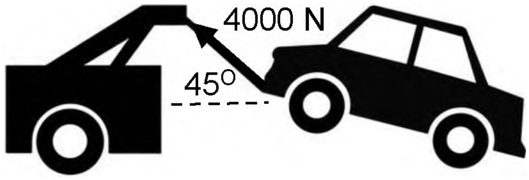
3.3 Determine the frictional force between the skateboard and the rail as she slides down the rail at constant velocity. (2)

3.4 Determine the normal force acting on the girl-skateboard system. (4)

3.5 Hence, calculate the coefficient of sliding friction between the rail and the skateboard. (3)

QUESTION 4

A car of mass 1000kg is towed by a tow truck with a force of 4000 N, applied at 45^{O} to the ground. The coefficient of friction between the car tyres and the ground is 0,4.



4.1 Draw a free-body diagram of the forces acting on the car, as it is towed. (4)

4.2 Determine the vertical component of the force applied to the car by the tow truck. (2)

4.3 Calculate the normal force acting on the car. (4)

4.4 Calculate the frictional force between the car tyres and the road as the car is towed. (4)

4.5 Will the car move when this force is applied by the tow truck? (2)

APPENDIX K: Grade 11 Examination August 2019

QUESTION 1 MULTIPLE CHOICE QUESTIONS

(I have included only those relevant to Newton's Laws)

1.2 A child of mass 20 kg slides down a smooth vertical pole at a constant velocity of 0,5 m/s. The average force exerted by the pole on the child is

A. 0 N
B. 10 N
C. 98 N
D. 196 N

1.3 On its own, a tow-truck has a maximum acceleration of 3 $m.s^{-2}$. While towing a vehicle of equal mass, the tow-truck will have a maximum acceleration of …

A. 6,0 $m.s^{-2}$
B. 2,0 $m.s^{-2}$
C. 1,5 $m.s^{-2}$
D. 1,0 $m.s^{-2}$

1.4 A box with a mass m is resting on a slope that is inclined at 30^{O} to the ground. The normal force is

A. mg
B. mg.sin30°
C. mg.cos30°
D. mg.tan30°

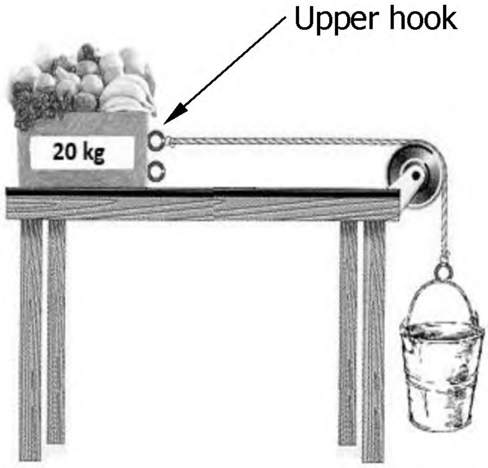
1.7 A mass is placed on a frictionless slope inclined at 30^{0} to the horizontal. The mass is then released.

What is its acceleration down the slope?

A. 4,9 $m.s^{-2}$
B. 5,7 $m.s^{-2}$
C. 8,5 $m.s^{-2}$
D. 9,8 $m.s^{-2}$

QUESTION 3 FRUIT BASKET

A 20 kg box of fruit has two hooks attached to its side at different heights. It is connected to a bucket (with a mass of 0,5 kg) from the upper hook using a light, frictionless pulley, such that the light, inflexible rope is horizontal as shown alongside.



Between the box and the table top, the coefficient of maximum static friction is 0,3 and the coefficient of kinetic friction is 0,1.

Sand is gradually added to the bucket until the box of fruit slides to the right. Once this motion starts, no more sand is added.

3.1 Calculate the magnitude of the normal force acting on the box of fruit. (2)

3.2 Determine the maximum frictional force acting on the box of fruit at the moment before it begins to slide. (3)

3.3 Calculate the mass of sand that is added to the bucket in order to make the box slide. (4)

3.4 Calculate the magnitude of the acceleration of the box once it starts to slide. (5)

The rope is now connected to the lower hook on the box.

3.5 Draw a free-body diagram of the forces acting on box now that the rope is connected to the lower hook. (4)

3.6 How would the magnitude of the acceleration of the box be affected now that the rope is attached to the lower hook? Assume the mass of sand in the bucket is equal to that calculated in (3.2.). Write *increase*, *decrease* or *remain the same* and explain your answer. (3)

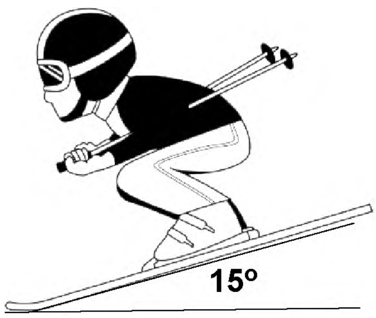
As the fruit box begins to accelerate, some fruit falls off the box.

3.7 Predict whether the fruit will land to the left or to the right of the box and use Newton's first law of motion to explain your answer. (3)

24 marks

QUESTION 4 JUNIOR DOWNHILL CHAMPS

At the Junior Downhill Skiing World Cup, the final skier of the day, with a mass of 50 kg, completed their downhill "run" of 1 km in an eye-watering 70 seconds!



4.1 Draw a labelled free-body diagram of the forces acting on the skier. (3)

4.2 Determine the perpendicular components of the weight of the skier. (4)

4.3 If the skier is travelling down the slope at a constant velocity, what frictional force is she experiencing? (2)

4.4 Determine the average velocity of the skier as they ski down the slope. (4)

The skier reaches the bottom of the slope, which is a flat horizontal area. She is travelling at 12 m/s horizontally, but fails to slow down before she hits an inflatable barrier, which makes her bounce back at 2 m/s. The impact with the barrier lasts 0,5 seconds.

4.5 State *Newton's second law of motion*. (2)

4.6 Determine the change in momentum of the skier. (4)

4.7 Impacts exceeding 2000 **N** usually result in serious injury. Calculate the magnitude and the direction of the force that the junior skier experiences in the collision with the inflatable barrier and state whether a serious injury is expected. (4)

4.8 State the *principle of conservation of momentum*. (2)

4.9 If the inflatable barrier had a mass of 100kg, what would the velocity of the barrier be after the skier hits it? (4)

4.10 The organisers of the event replace the inflatable barrier with a sponge barrier. This sponge barrier brings a skier with the same mass, travelling with the same initial velocity <u>to rest</u> in 0,5 seconds. Will the force that the sponge barrier exerts on the skier be **less than**, **greater than** or **equal to** the force that the inflatable barrier exerted on the skier? Briefly explain your choice. (2)

31 marks

It always seems impossible until it is done.

Nelson Mandela (1918 – 2013)